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(54) **ELECTROSTATIC PRECIPITATORS WITH INSULATED DRIVER ELECTRODES**

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See application file for complete search history.

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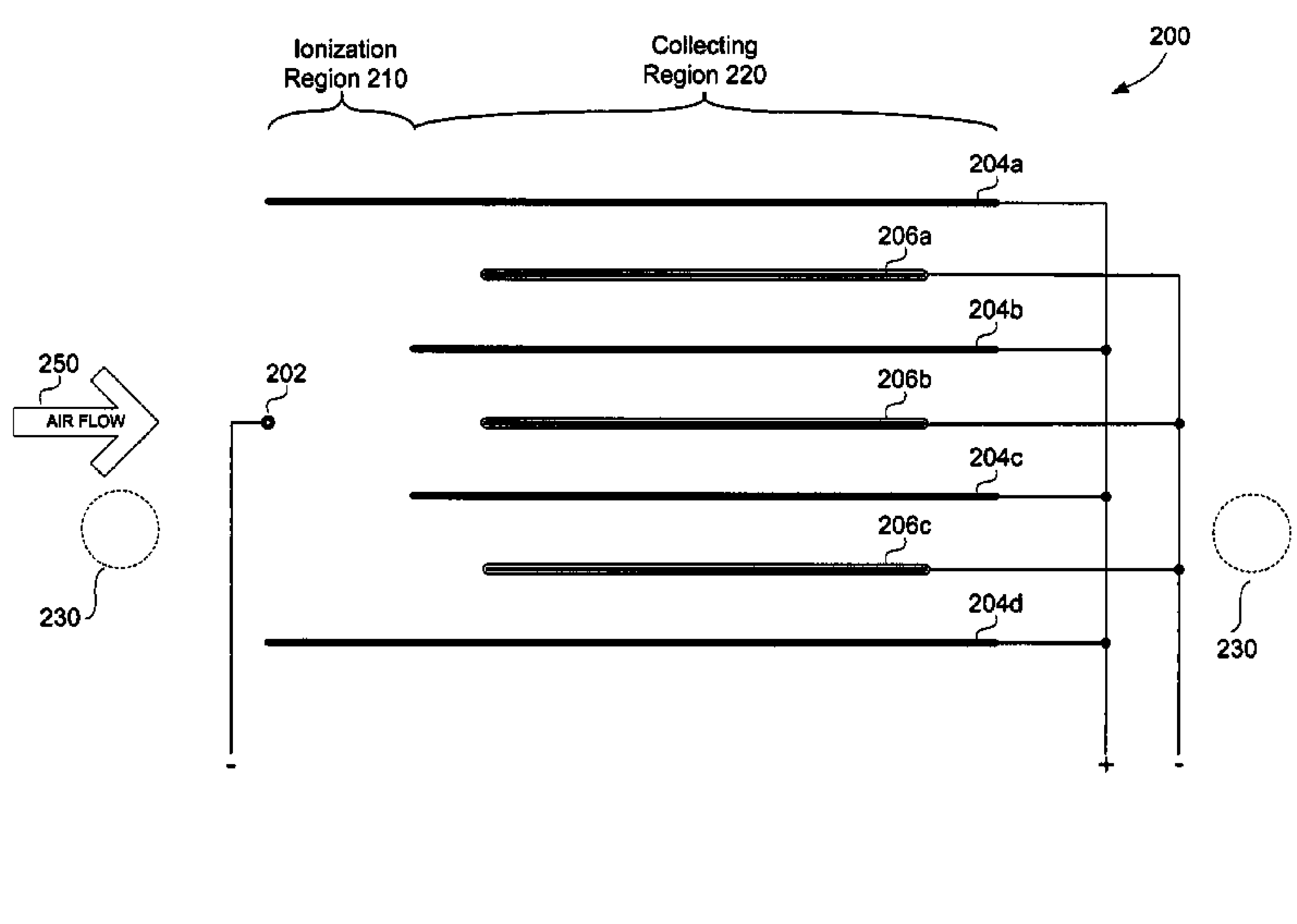
(57) **ABSTRACT**

Electrostatic precipitator (ESP) systems and methods are provided. A system includes at least one corona discharge electrode and at least one collector (and likely, at least a pair of collector electrodes) that extend downstream from the corona discharge electrode. An insulated driver electrode is located adjacent the collector electrode, and where there is at least a pair of collector electrodes, between each pair of collector electrodes. A high voltage source provides a voltage potential to the at least one of the corona discharge electrode and the collector electrode(s), to thereby provide a potential different therebetween. The insulated driver electrode(s) may or may not be at a same voltage potential as the corona discharge electrode, but should be at a different voltage potential than the collector electrode(s).

18 Claims, 20 Drawing Sheets



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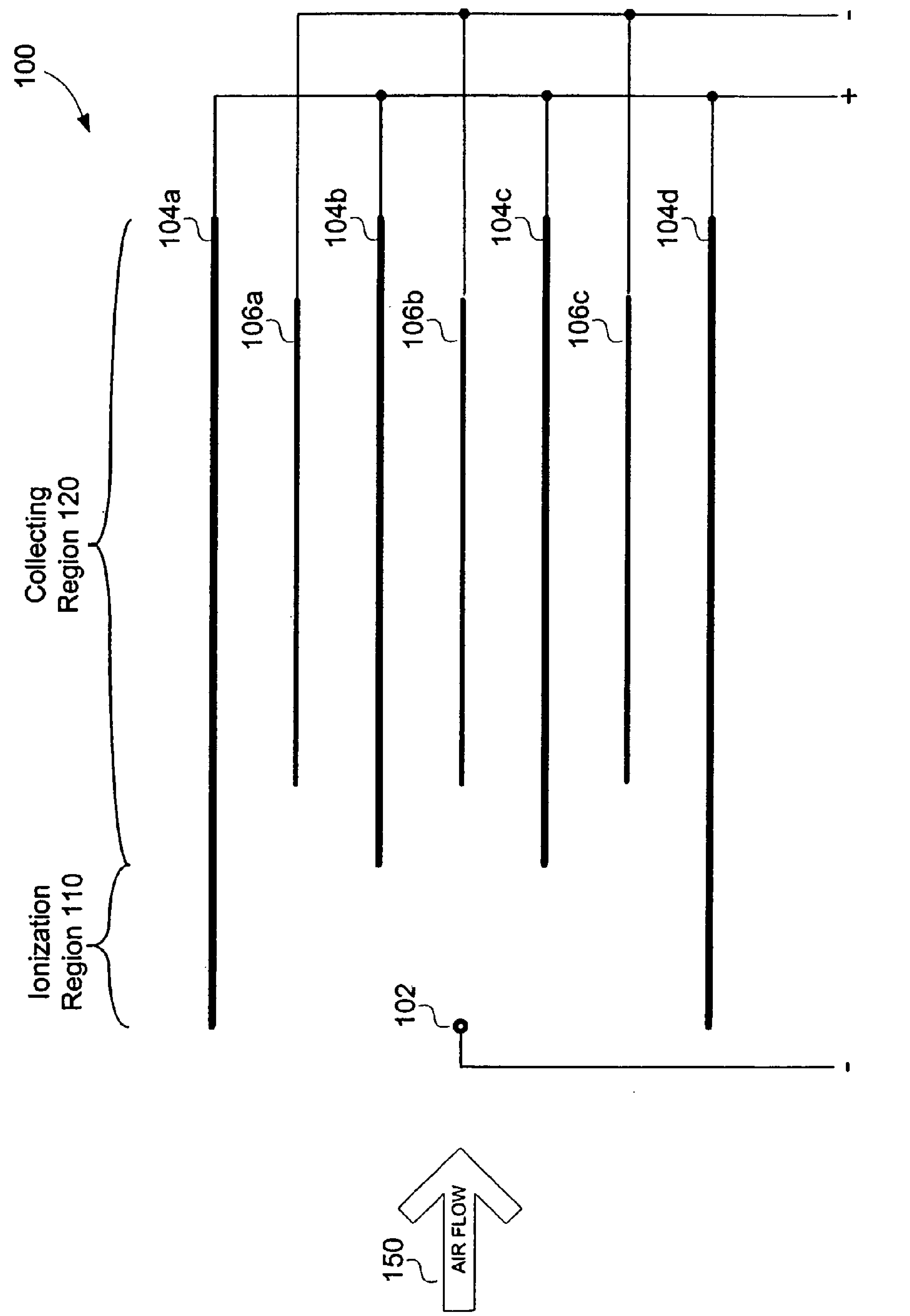


FIG. 1A
PRIOR ART

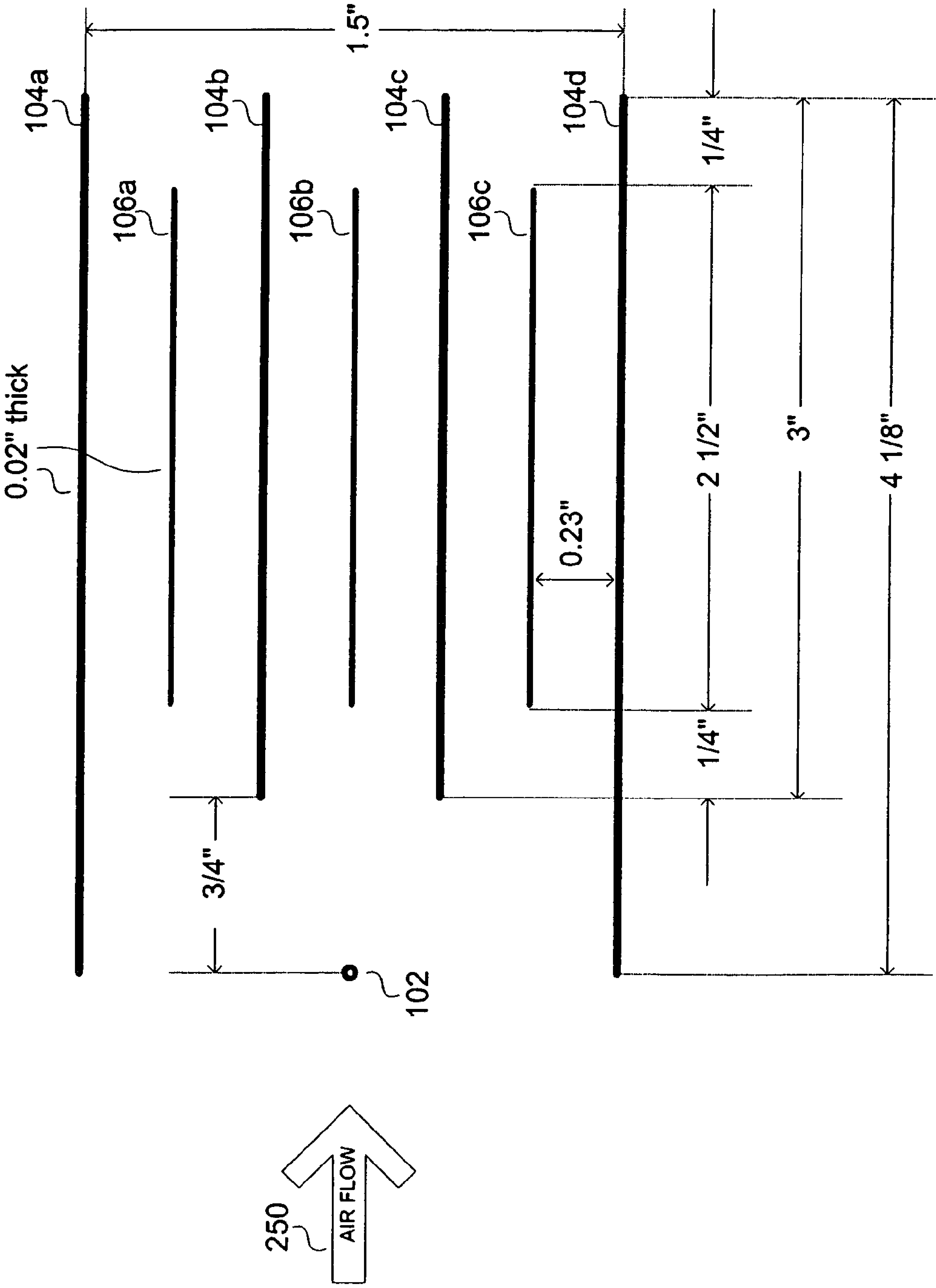


FIG. 1B

PRIOR ART

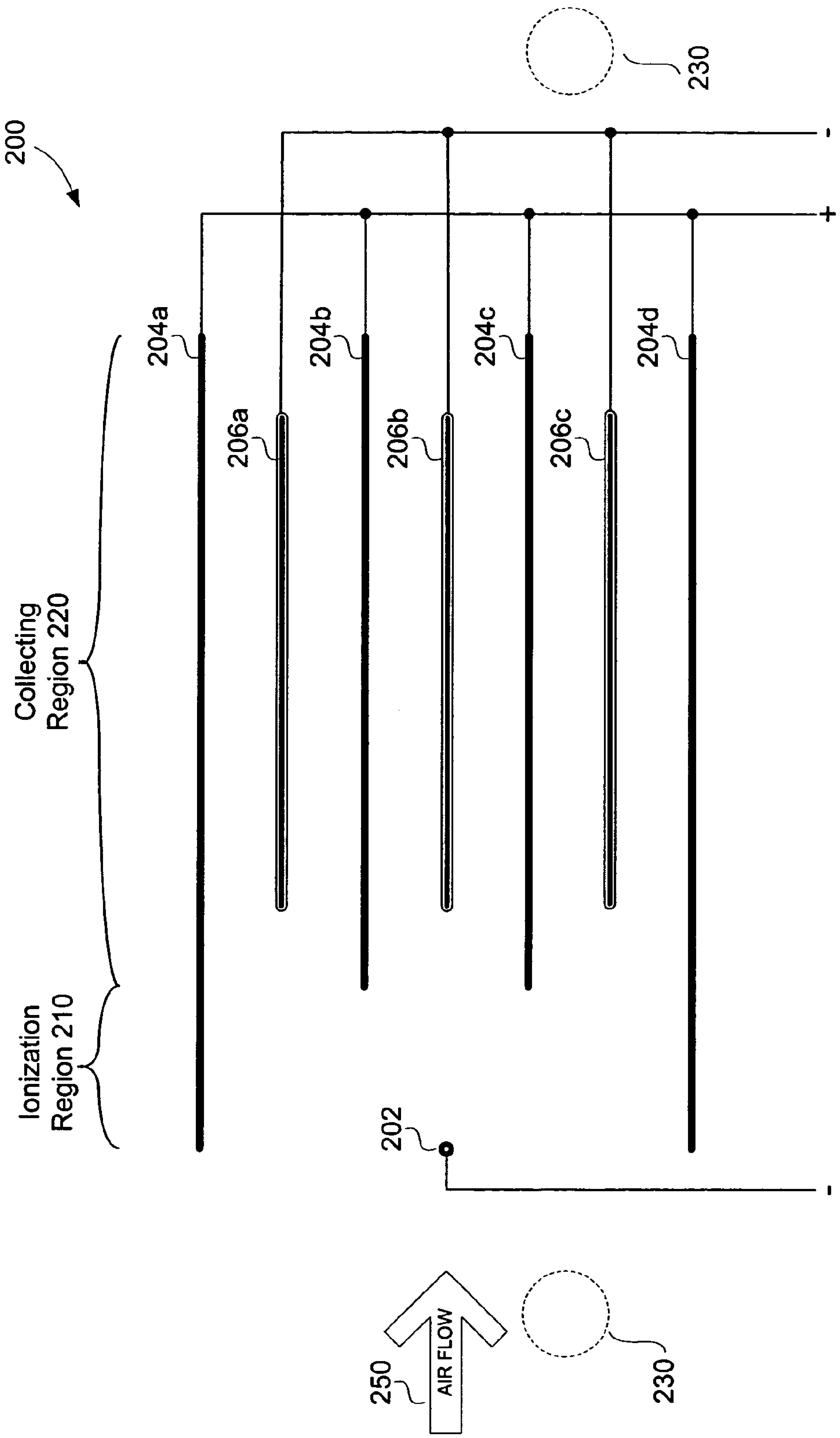

200
230
-
+
204a
206a
204b
206b
204c
206c
204d
Collecting Region 220
Ionization Region 210
202
-
250
AIR FLOW
230

FIG. 2A

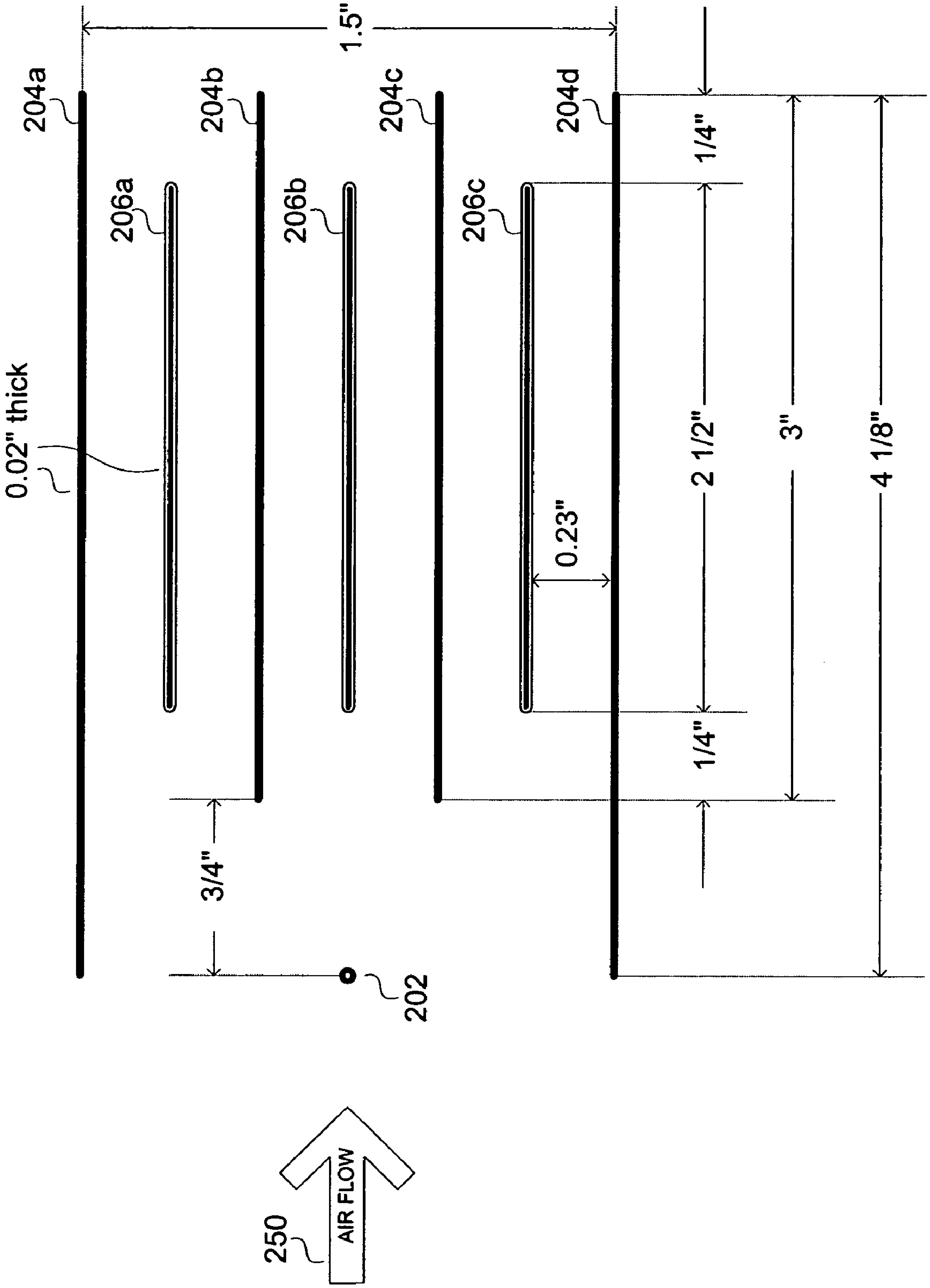

1.5"
204a
204b
204c
204d
206a
206b
206c
0.02" thick
0.23"
1/4"
2 1/2"
3"
4 1/8"
1/4"
3/4"
202
250
AIR FLOW

FIG. 2B

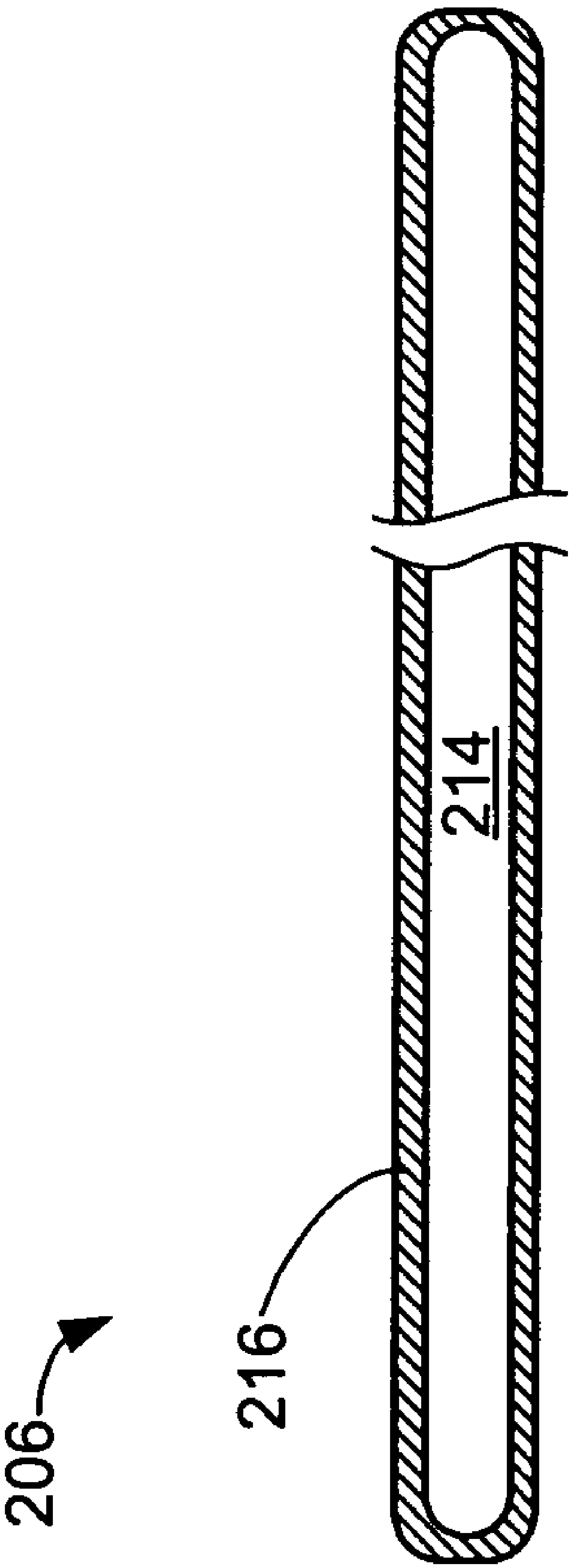


FIG. 2C

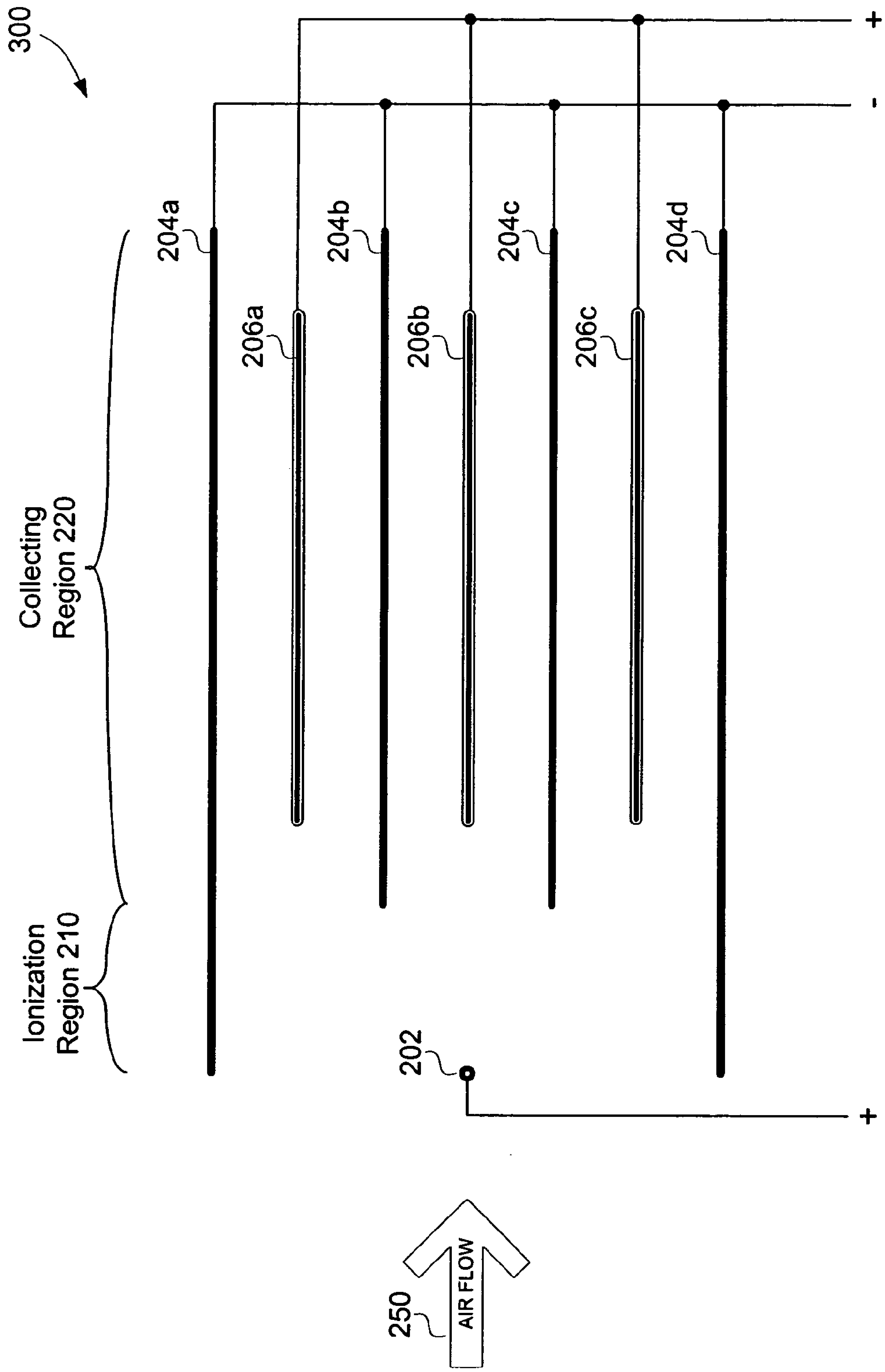

300
Collecting Region 220
Ionization Region 210
204a
204b
204c
204d
206a
206b
206c
202
+
-
+
250
AIR FLOW

FIG. 3

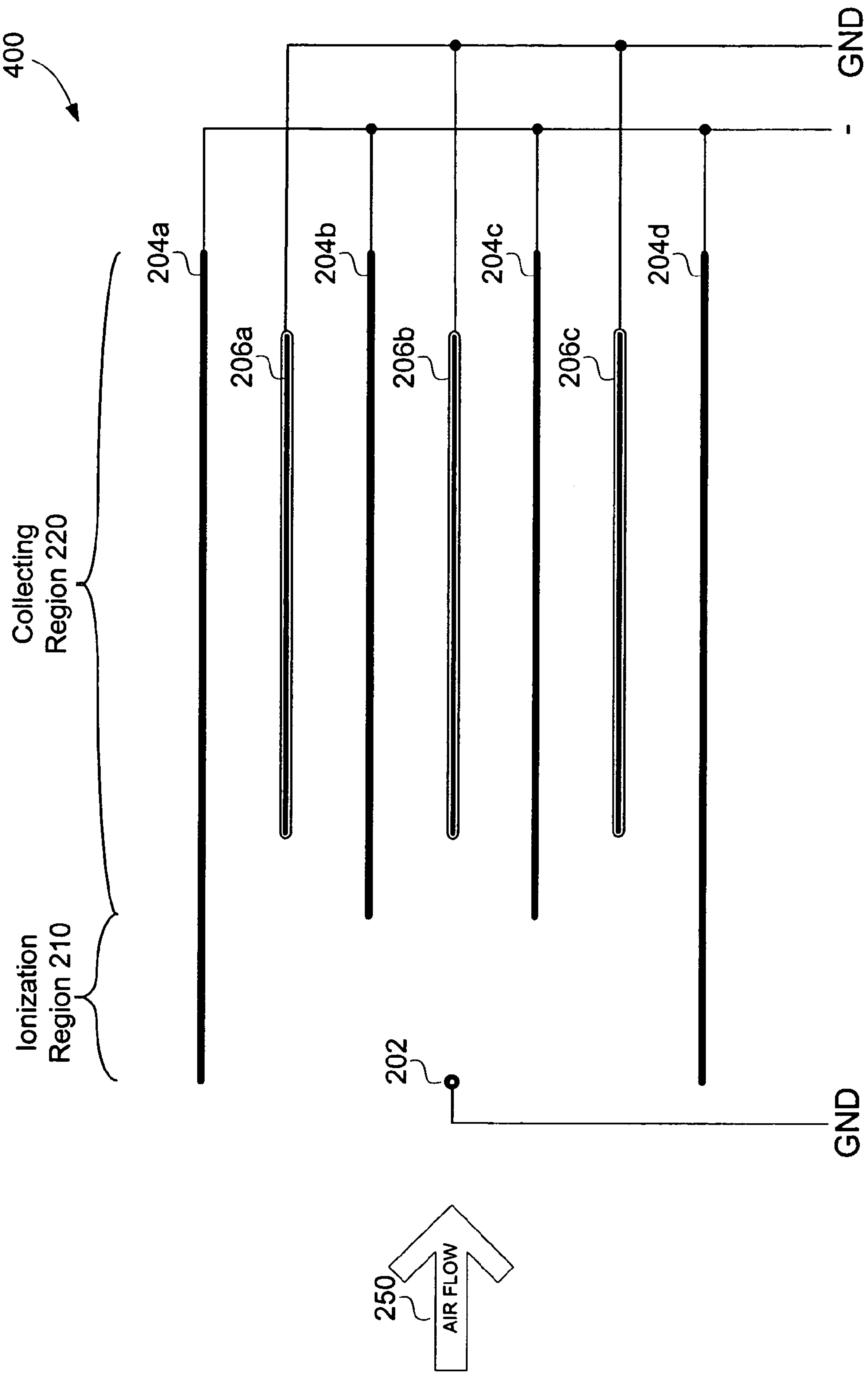

400
GND
-
204a
204b
204c
204d
206a
206b
206c
Collecting Region 220
Ionization Region 210
202
GND
250
AIR FLOW

FIG. 4

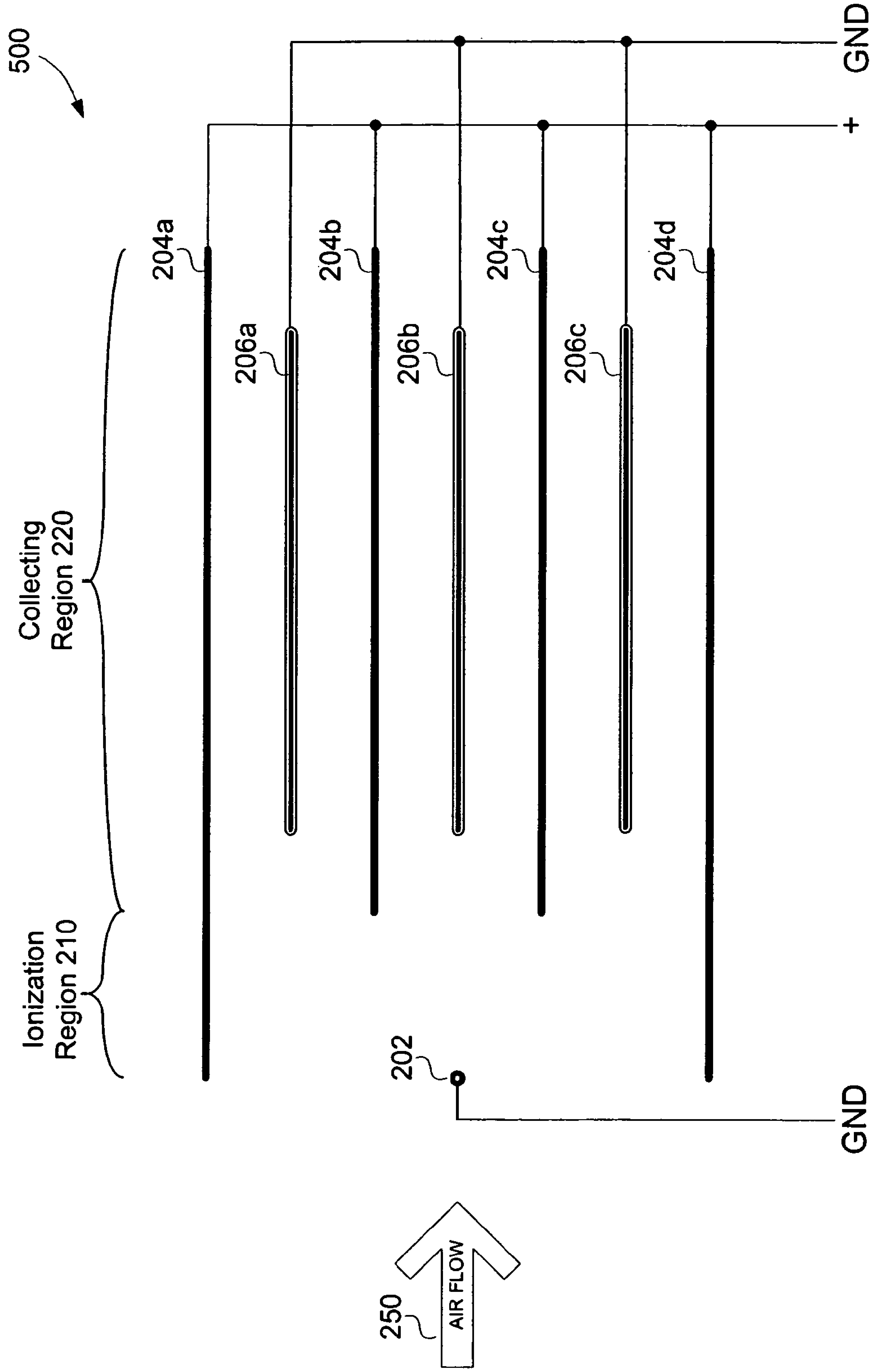

500
GND
+
204a
204b
204c
204d
206a
206b
206c
Collecting Region 220
Ionization Region 210
202
GND
250
AIR FLOW

FIG. 5

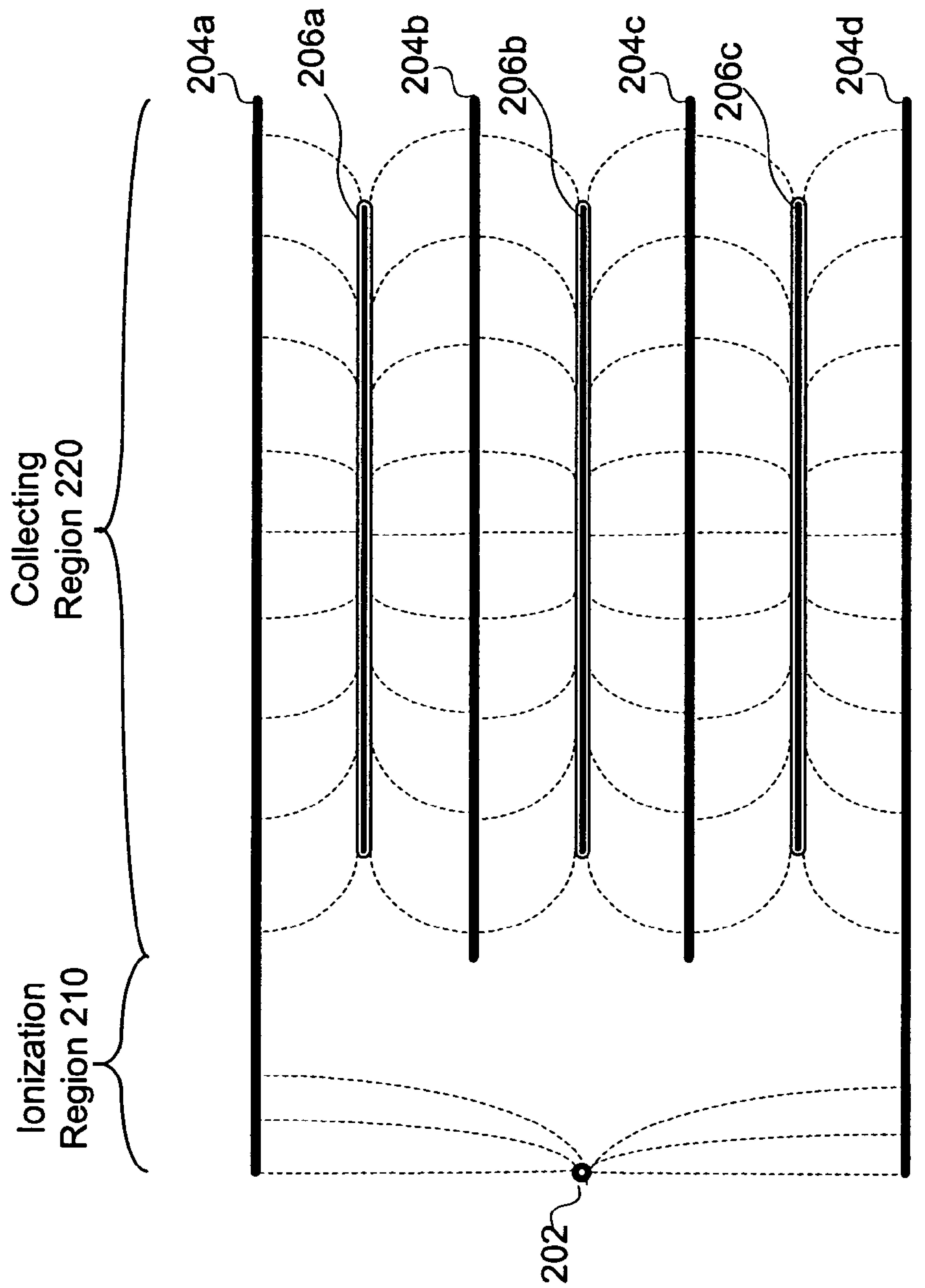

Collecting Region 220
Ionization Region 210
204a
206a
204b
206b
204c
206c
204d
202

FIG. 6

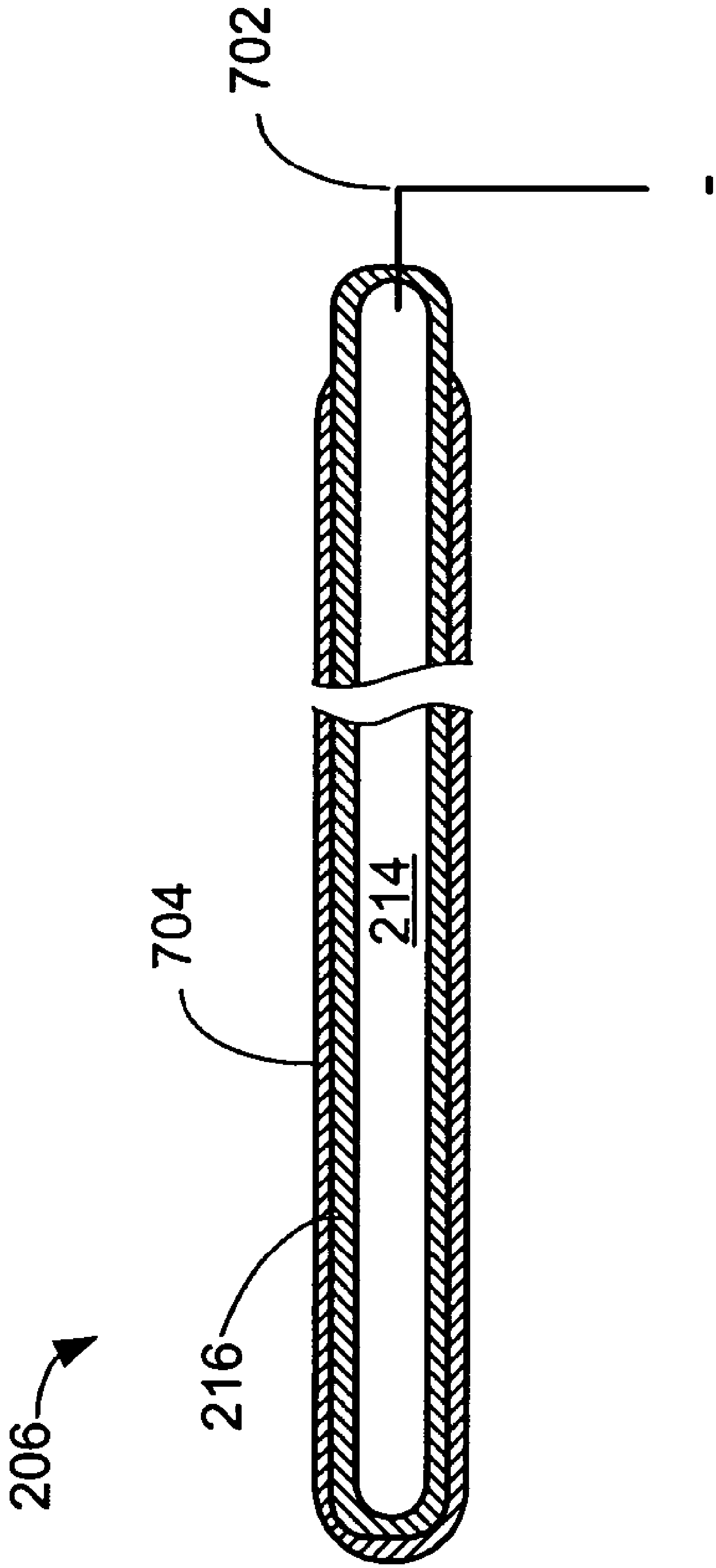


FIG. 7

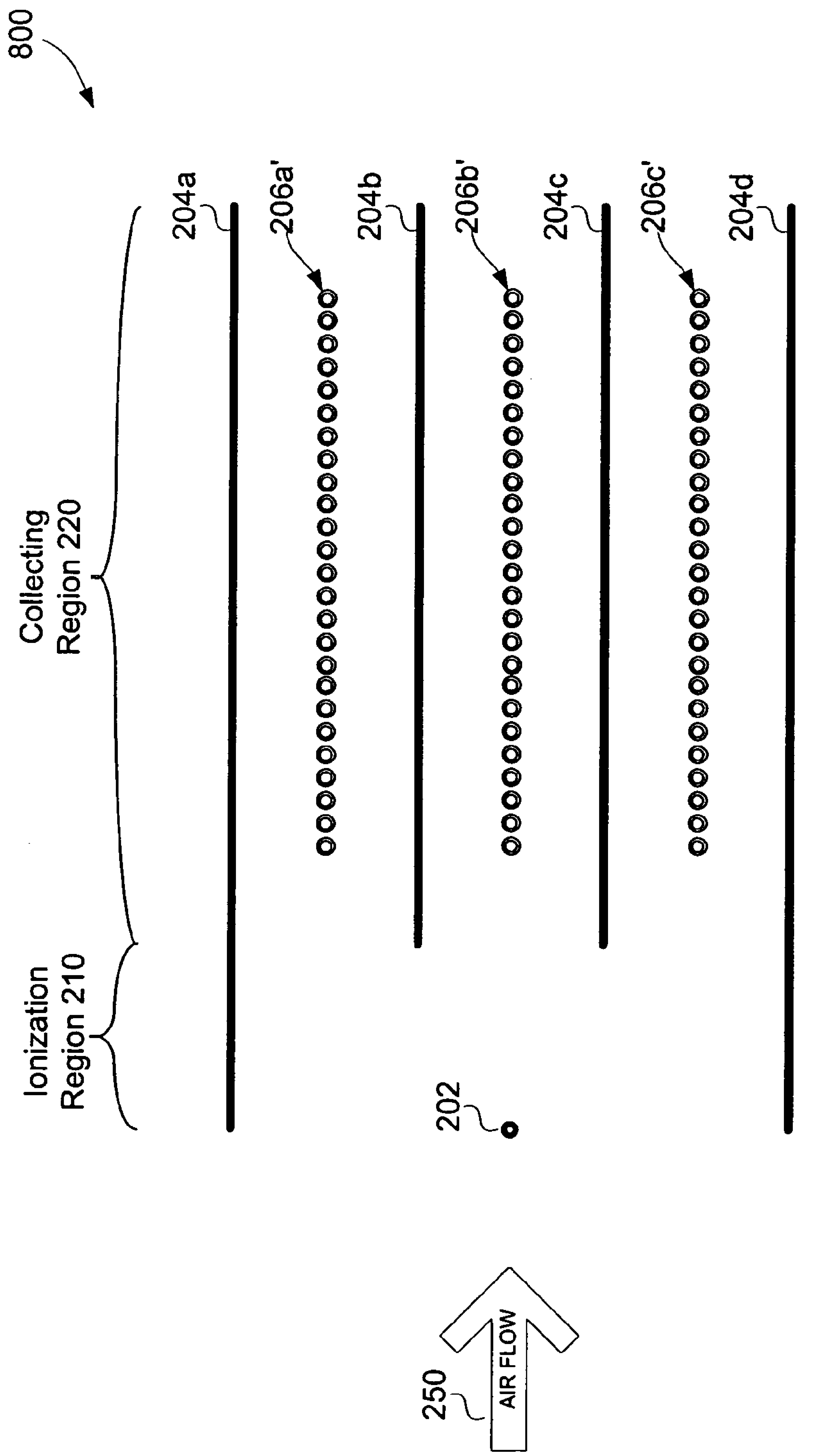

800
Collecting Region 220
Ionization Region 210
204a
206a'
204b
206b'
204c
206c'
204d
202
250
AIR FLOW

FIG. 8

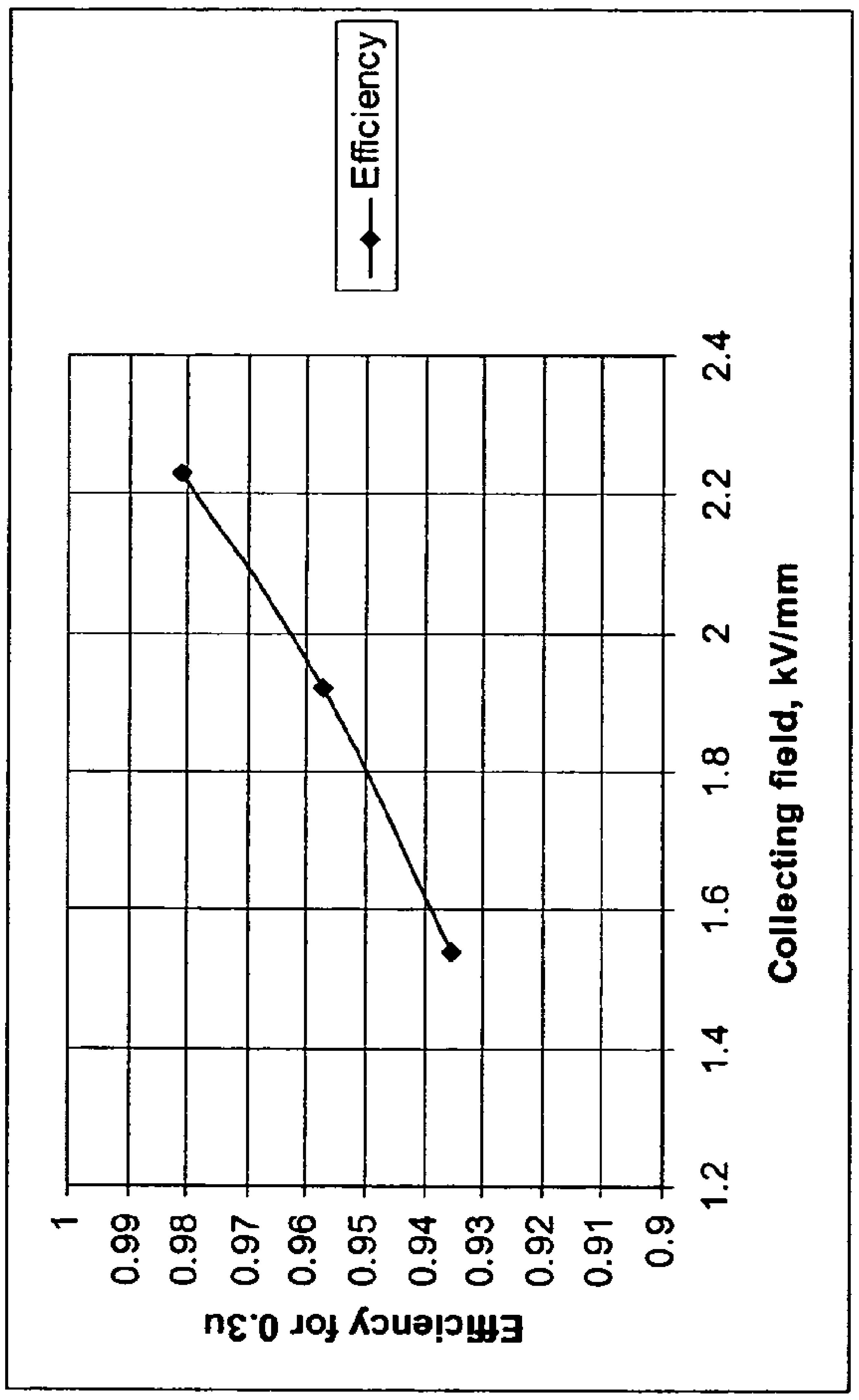

Efficiency
Efficiency for 0.3u
Collecting field, kV/mm
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
1.2
1.4
1.6
1.8
2
2.2
2.4

FIG. 9A

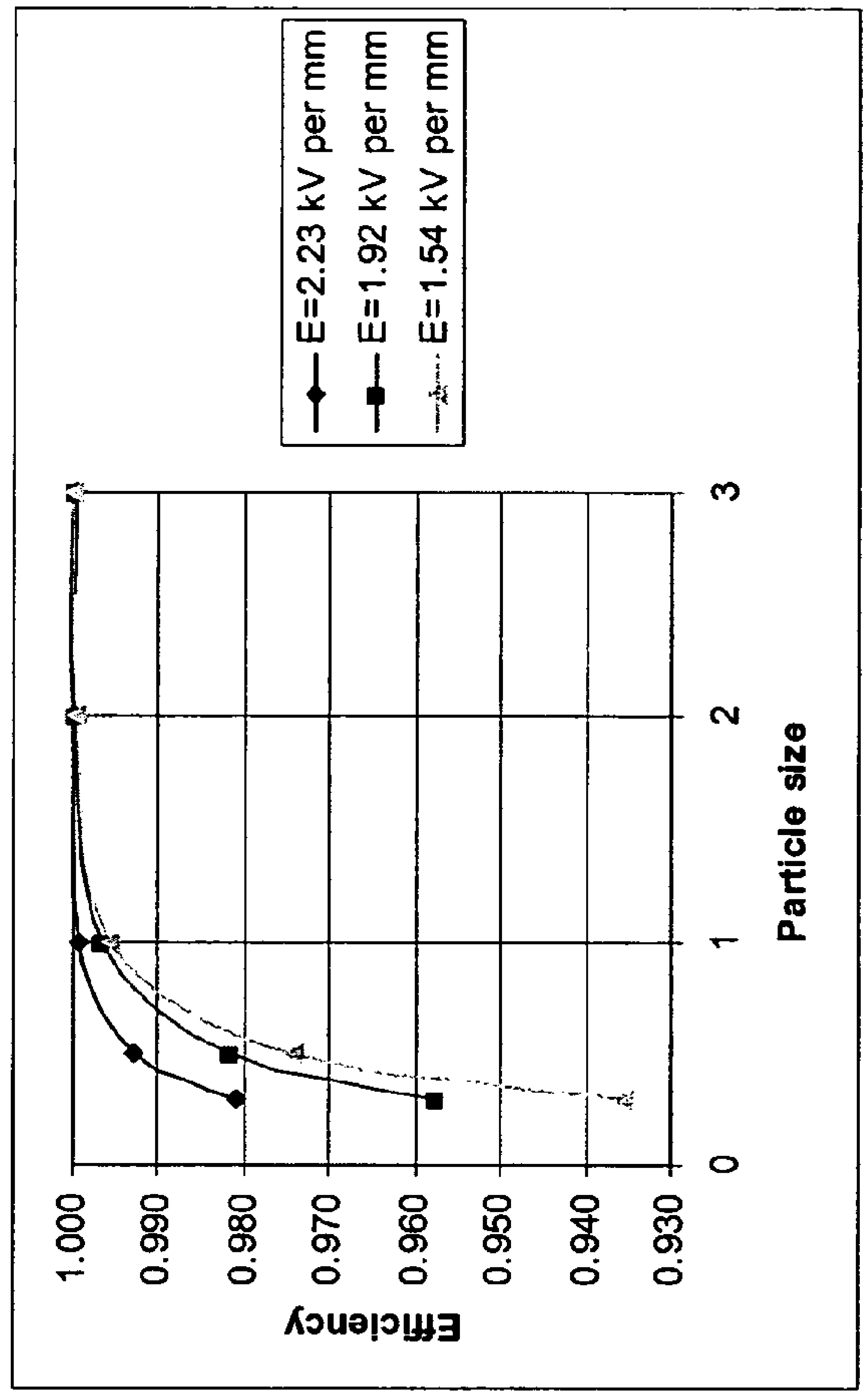

E=2.23 kV per mm
E=1.92 kV per mm
E=1.54 kV per mm
Efficiency
Particle size
1.000
0.990
0.980
0.970
0.960
0.950
0.940
0.930
0
1
2
3

FIG. 9B

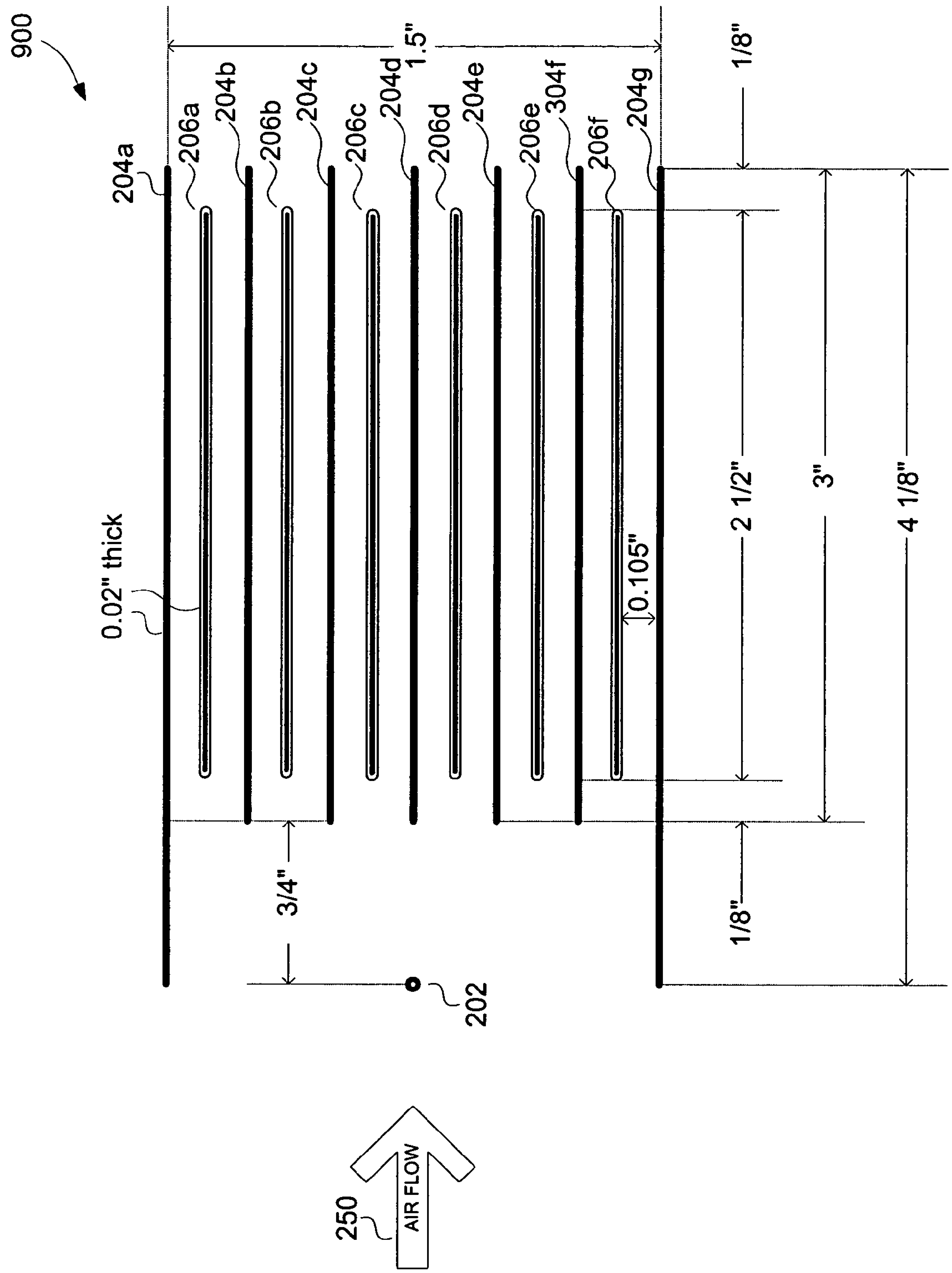

900
1.5"
1/8"
204a
206a
204b
206b
204c
206c
204d
206d
204e
206e
304f
206f
204g
0.02" thick
0.105"
2 1/2"
3"
4 1/8"
3/4"
1/8"
202
250
AIR FLOW

FIG. 10

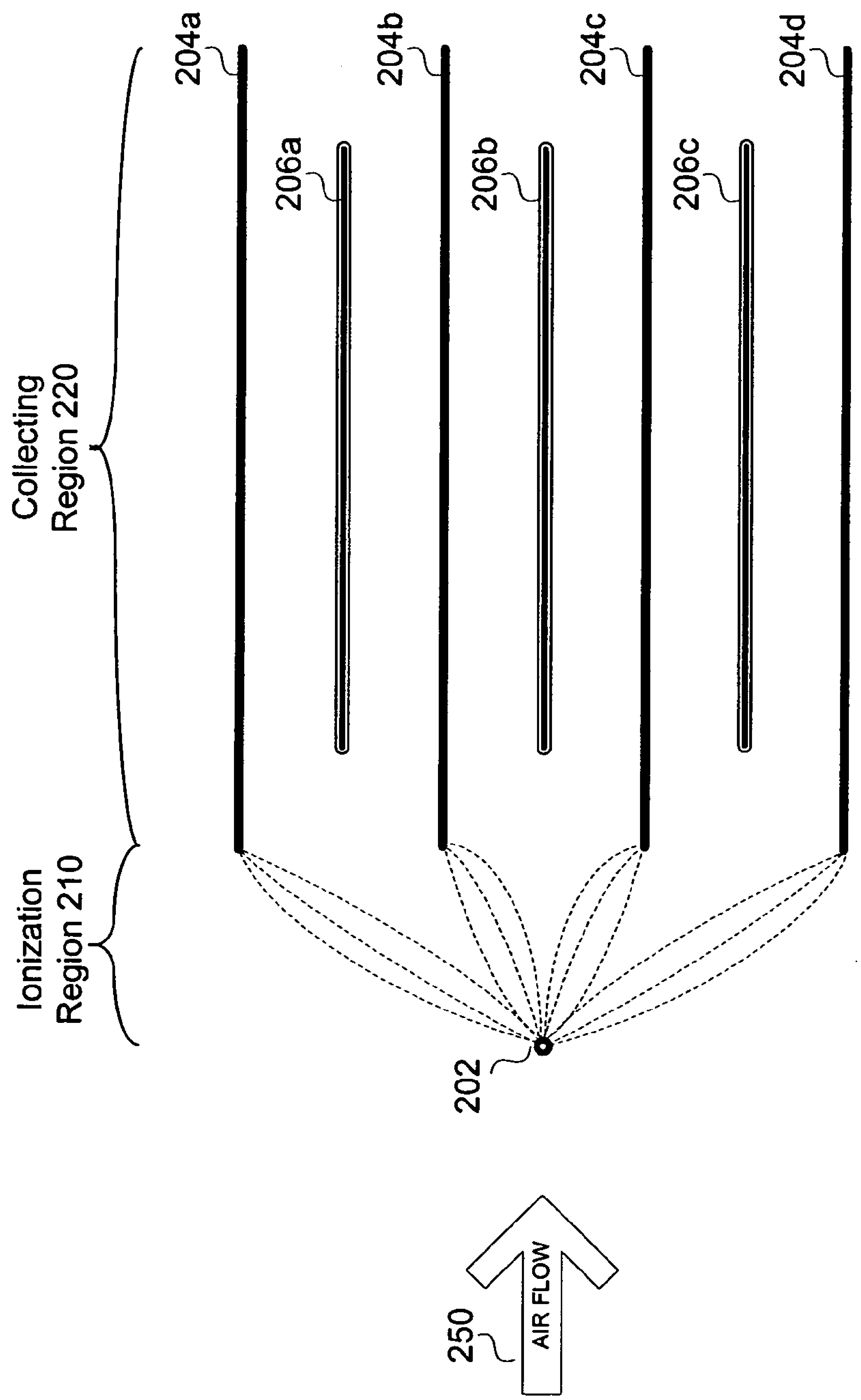

204a
204b
204c
204d
206a
206b
206c
Collecting Region 220
Ionization Region 210
202
250
AIR FLOW

FIG. 11

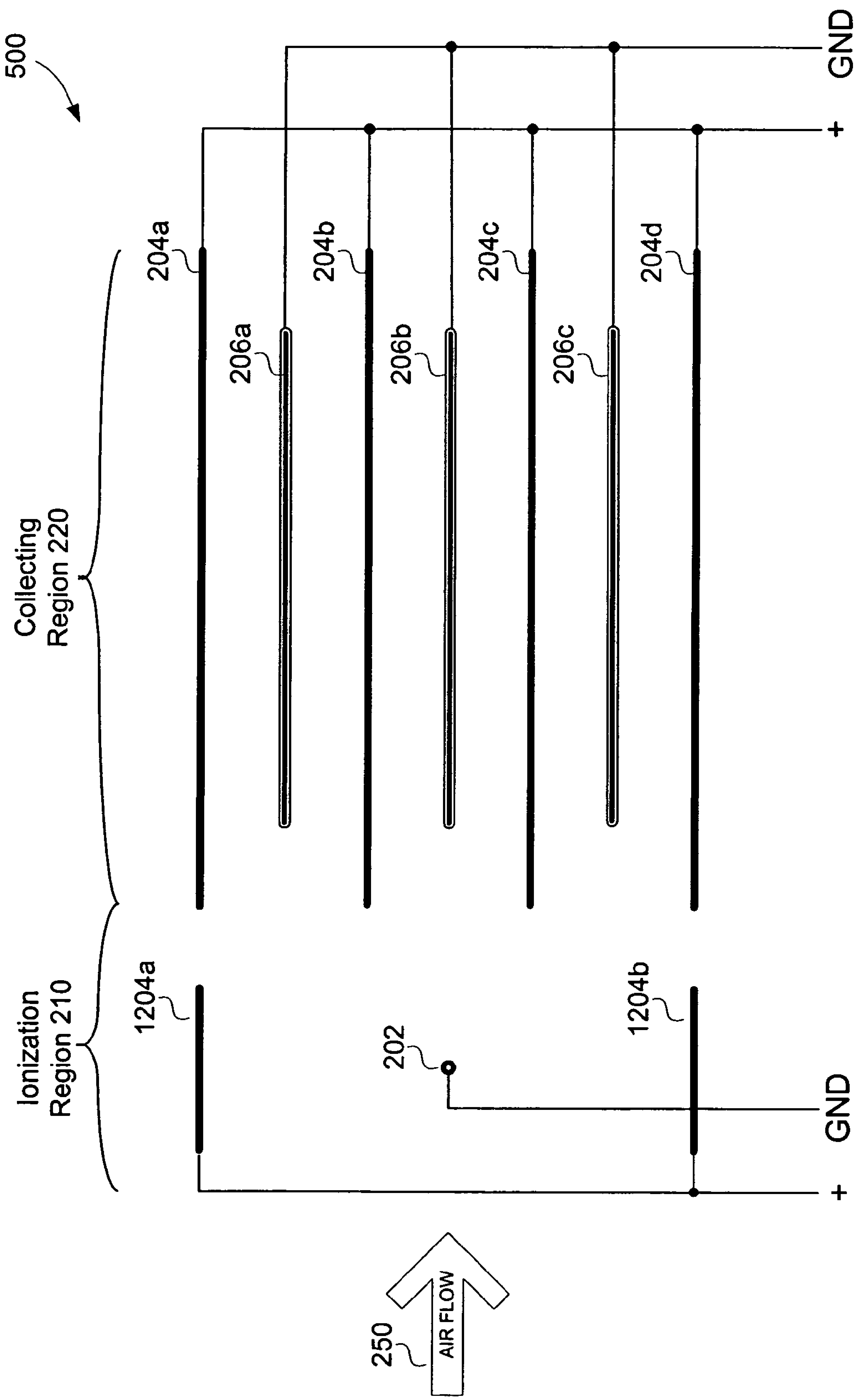
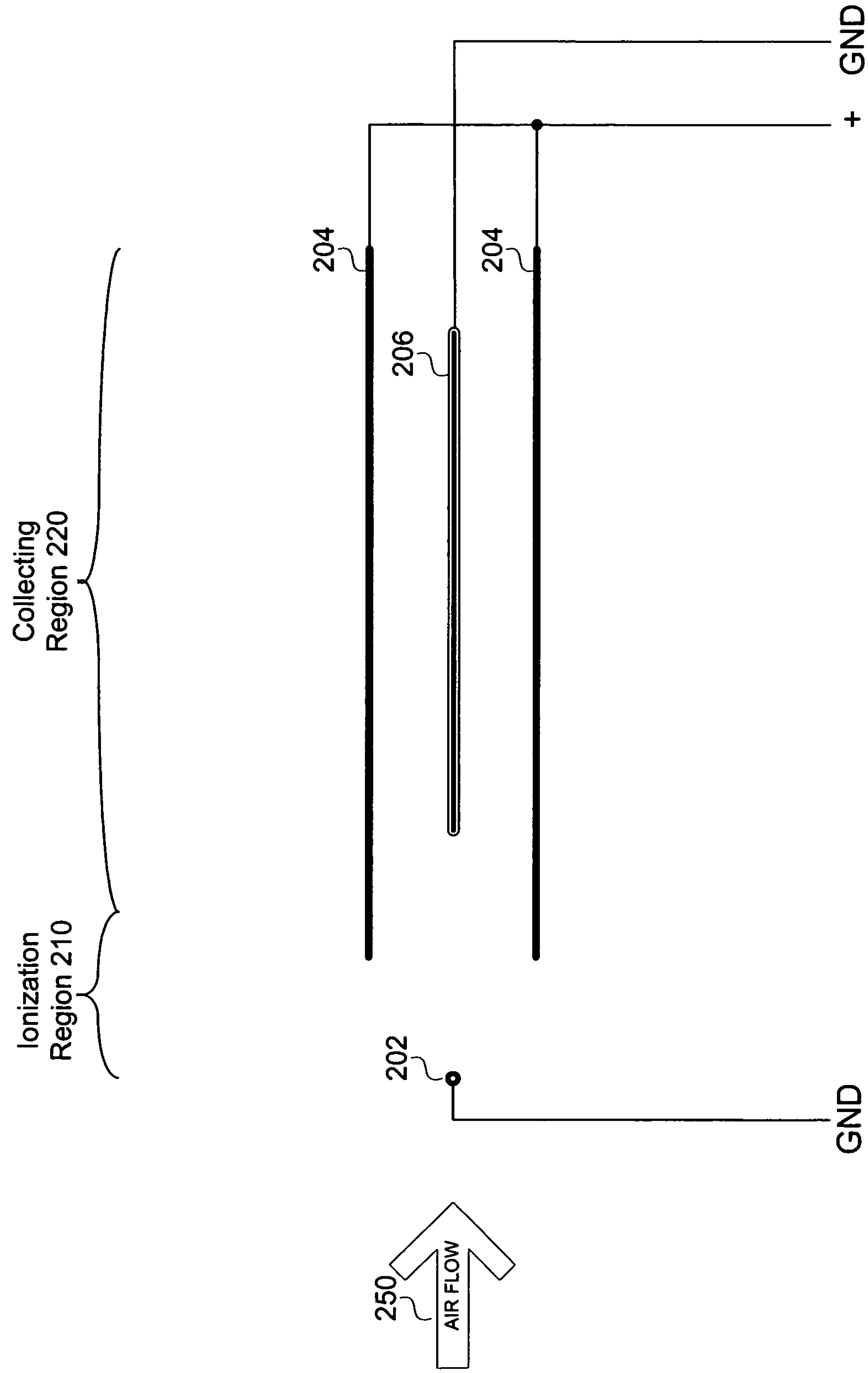

500
Collecting Region 220
Ionization Region 210
204a
206a
204b
206b
204c
206c
204d
1204a
1204b
202
GND
+
GND
+
250
AIR FLOW

FIG. 12



Collecting Region 220
Ionization Region 210
204
206
204
202
GND
+
GND
AIR FLOW
250

FIG. 13

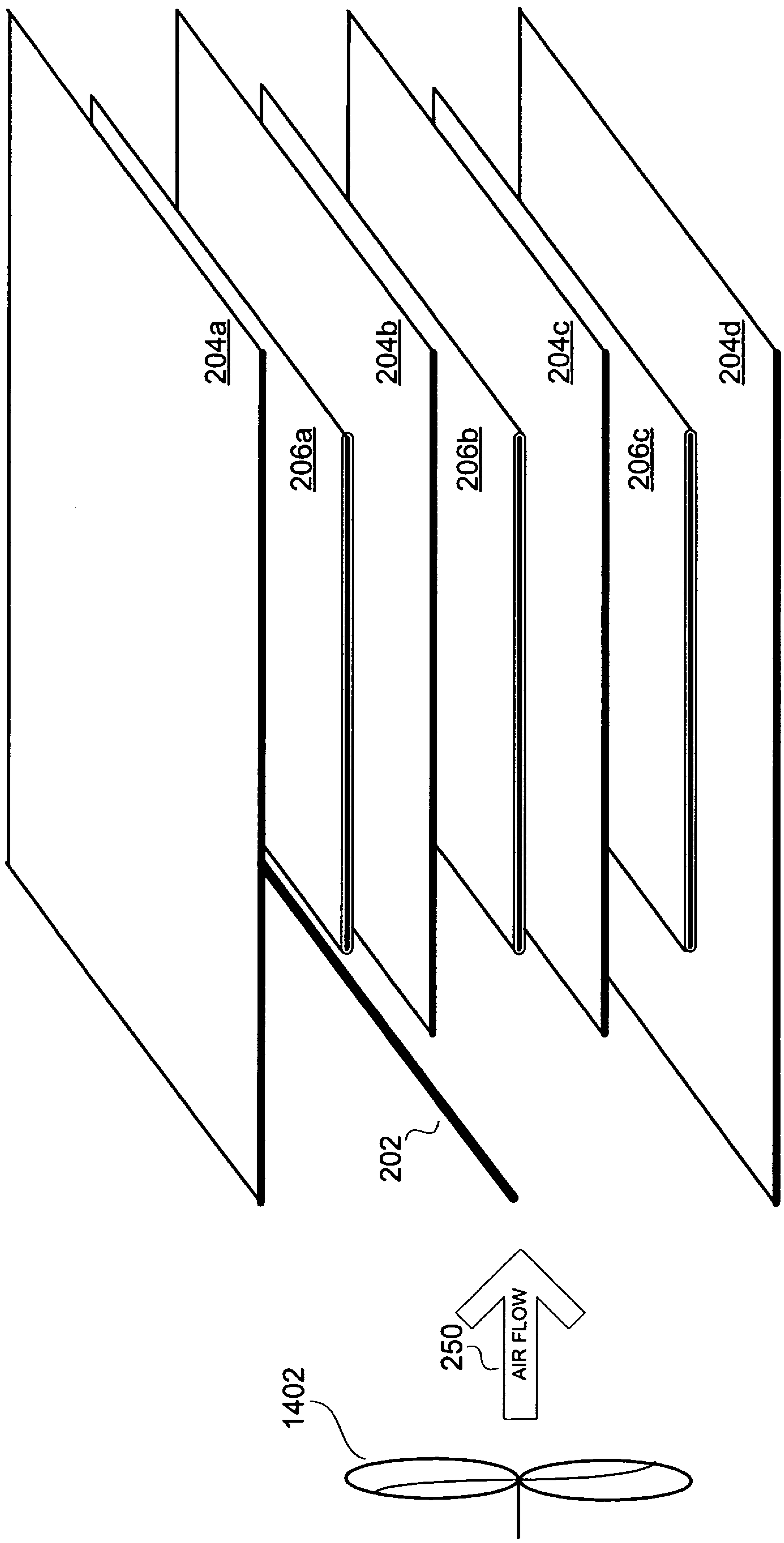


FIG. 14

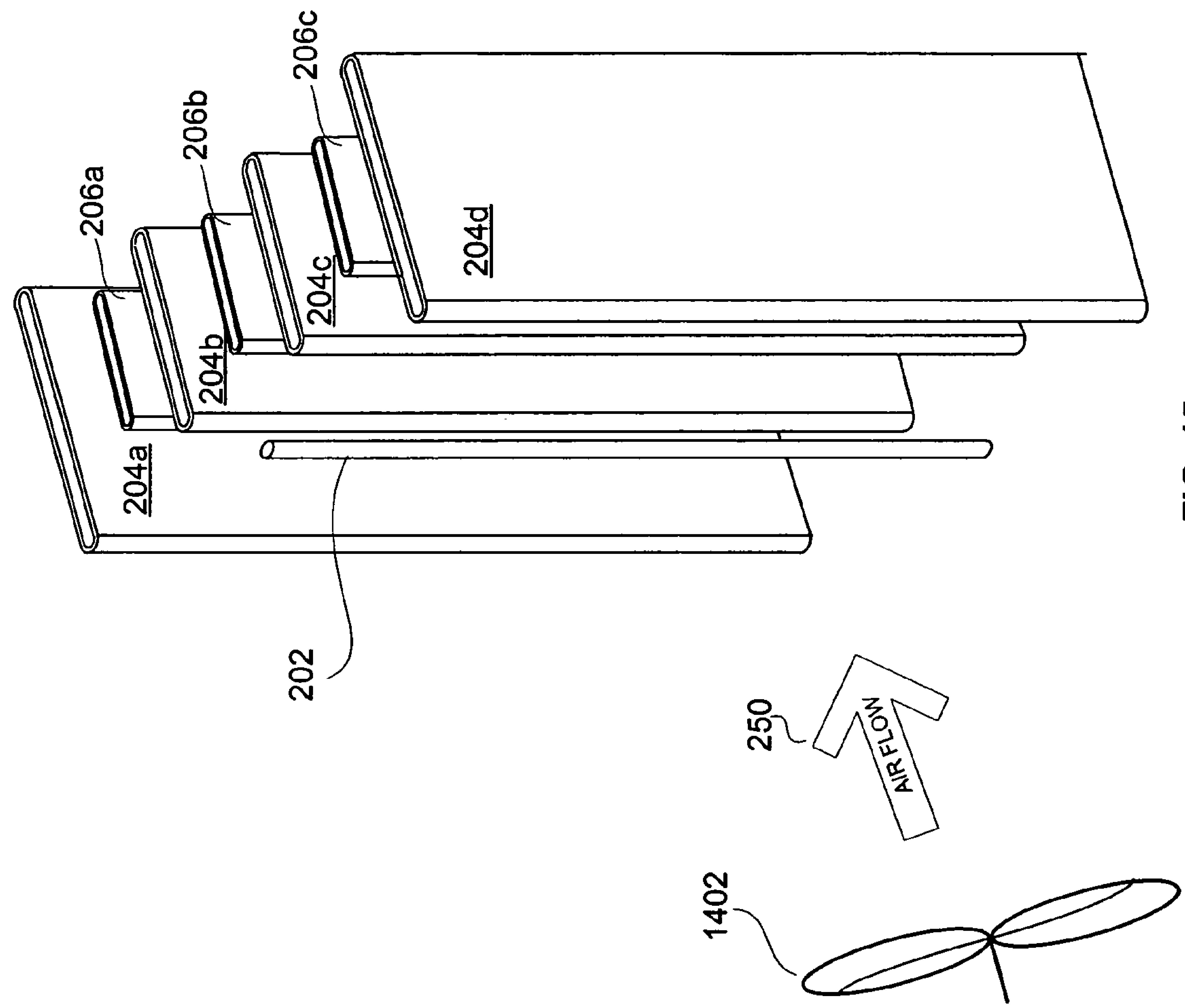
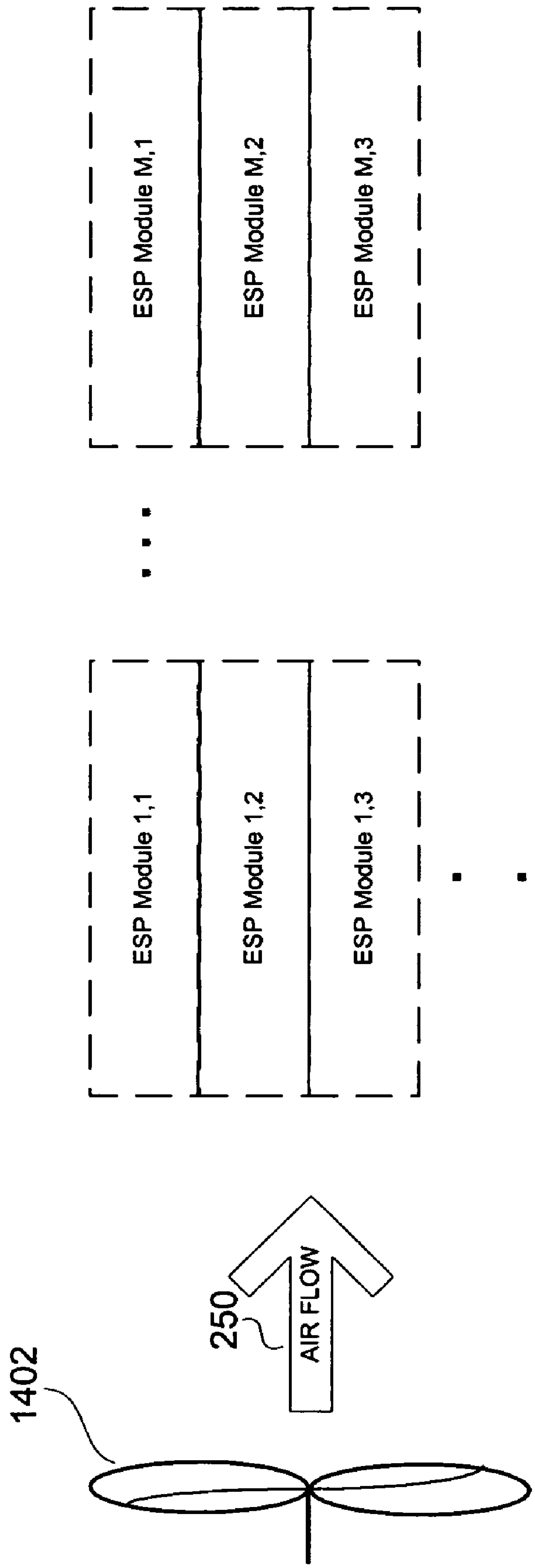


FIG. 15



ESP Module M,1
ESP Module M,2
ESP Module M,3
ESP Module M,N
ESP Module 1,1
ESP Module 1,2
ESP Module 1,3
ESP Module 1,N
250
AIR FLOW
1402

FIG. 16

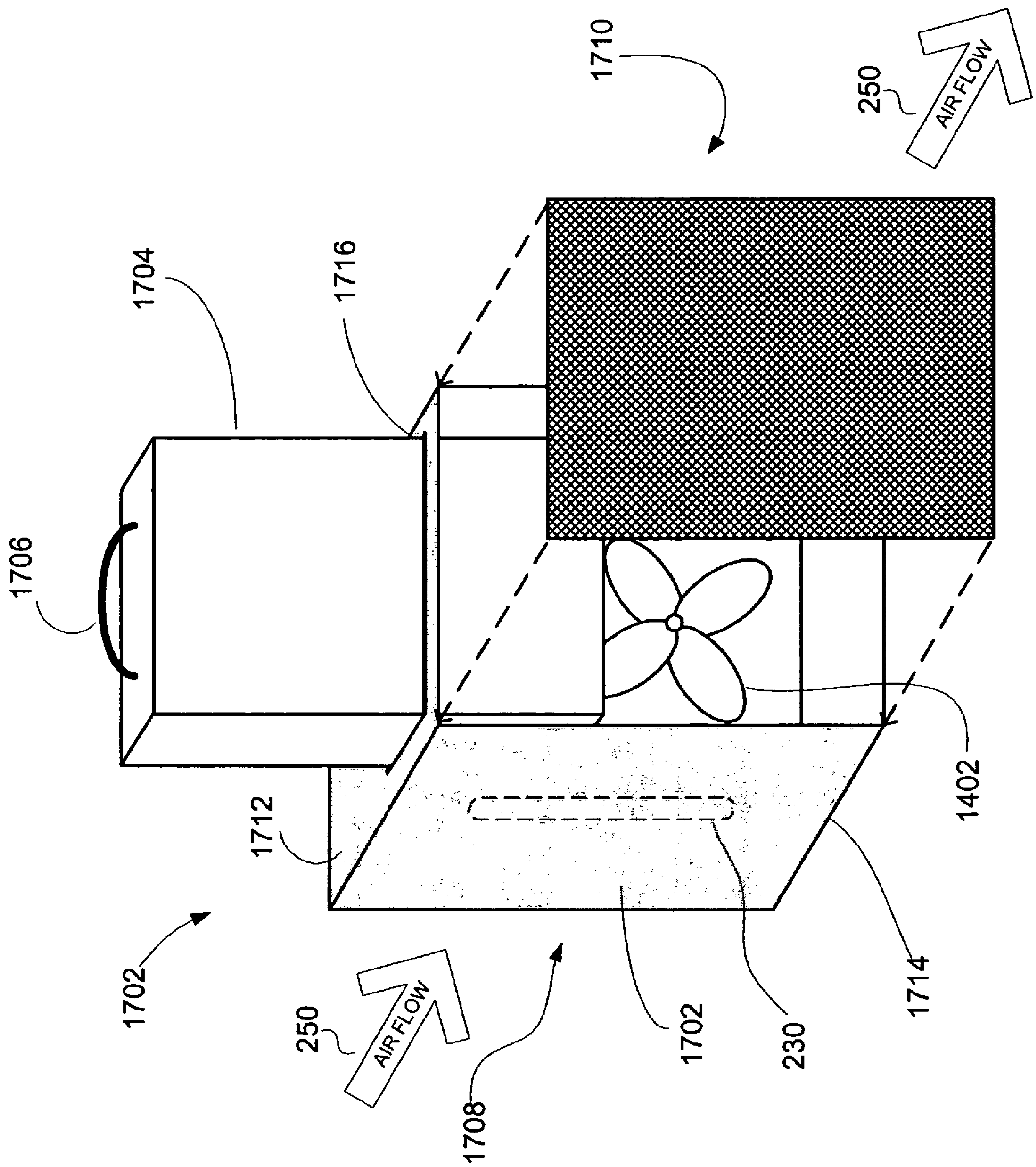

1710
250
AIR FLOW
1704
1716
1706
1402
1712
1702
250
AIR FLOW
1708
1702
230
1714

FIG. 17

ELECTROSTATIC PRECIPITATORS WITH INSULATED DRIVER ELECTRODES

PRIORITY CLAIM

The present application is a continuation-in-part of U.S. patent application Ser. No. 10/717,420 filed Nov. 19, 2003, entitled "Electro-Kinetic Air Transporter and Conditioner Devices with Insulated Driver Electrodes", which claims priority under 35 U.S.C. 119(e) to U.S. Provisional Patent Application No. 60/500,437, filed Sep. 5, 2003, entitled "Electro-Kinetic Air Transporter and Conditioner Devices with Insulated Driver Electrodes", both of which are incorporated by reference herein, and to both of which the present application claims priority.

CROSS-REFERENCE TO RELATED ART

The present invention is related to the following patent application and patent, each of which is incorporated herein by reference: U.S. patent application Ser. No. 10/074,207, filed Feb. 12, 2002, entitled "Electro-Kinetic Air Transporter-Conditioner Devices with Interstitial Electrode"; and U.S. Pat. No. 6,176,977, entitled "Electro-Kinetic Air Transporter-Conditioner."

FIELD OF THE INVENTION

The present invention relates generally to electrostatic precipitator (ESP) systems.

BACKGROUND OF THE INVENTION

An example of a conventional electrostatic precipitator (ESP), module or system **100** is depicted in simplified form in FIG. **1**A. The exemplary ESP module **100** includes a corona discharge electrode **102** (also known as an emitter electrode) and a plurality of collector electrodes **104**. A driver electrode **106** is located between each pair of collector electrodes. In the embodiment shown there are four collector electrodes **104***a*, **104***b*, **104***c* and **104***d*, and three driver electrodes **106***a*, **106***b* and **106***c*. The corona discharge electrode **102**, which is likely a wire, is shown as receiving a negative charge. The collector electrodes **104**, which are likely metal plates, are shown as receiving a positive charge. The driver electrodes **106**, which are also likely metal plates, are shown as receiving a negative charge. FIG. **1**B illustrates exemplary dimensions for the system or module of FIG. **1**A.

The voltage difference between the discharge electrode **102** and the upstream portions or ends of the collector electrodes **104** create a corona discharge from the discharge electrode **102**. This corona discharge ionizes (i.e., charges) the air in the vicinity of the discharge electrode **102** (i.e., within the ionization region **110**). As air flows through the ionization region **110**, in the direction indicated by an arrow **150**, particulate matter in the airflow is charged (in this case, negatively charged). As the charged particulate matter moves toward the collector region **120**, the particulate matter is electrostatically attracted to and collects on the surfaces of the collector electrodes **104**, where it remains, thus conditioning the flow of air. Further, the corona discharge produced by the electrode **102** can release ozone into the ambient environment, which can eliminate odors that are entrained in the airflow, but is generally undesirable in excess quantities. The driver electrodes **106**, which have a similar charge as the particles (negative, in this case) repel or push the particles toward the collector electrodes **104**, thereby increasing precipitation efficiency (also known as collection efficiency). However, because the negatively charged driver electrodes **106** are located close to adjacent positively charged collector electrodes **104**, undesirable arcing (also known as breakdown or sparking) will occur between the collector electrodes **104** and the driver electrodes **106** if the potential difference there-between is too high, or if a carbon path is produced between the a collecting electrode **104** and a driver electrode **106** (e.g., due to a moth or other insect that got stuck between an electrode **104** and electrode **106**, or due to dust buildup). It is also noted that driver electrodes **106** are sometimes referred to as interstitial electrodes, because they are situated between other (i.e., collector) electrodes.

Increasing the voltage difference between the driver electrodes **106** and the collector electrodes **108** is one way to further increase particle collecting efficiency. However, the extent that the voltage difference can be increased is limited because arcing will eventually occur between the collector electrodes **104** and the driver electrodes **106**. Such arcing will typically decrease the collecting efficiency of the system.

Accordingly, there is a desire to improve upon existing ESP techniques. More specifically, there is a desire to increase particle collecting efficiency and to reduce arcing between electrodes.

SUMMARY OF THE PRESENT INVENTION

Embodiments of the present invention are related to ESP systems and methods. In accordance with an embodiment of the present invention, a system includes at least one corona discharge electrode (also known as an emitter electrode) and at least one collector electrode that extends downstream from the corona discharge electrode. An insulated driver electrode is located adjacent the collector electrode. In embodiments where there are at least two collector electrodes, an insulated driver electrode is located between each pair of adjacent electrodes. A high voltage source provides a voltage potential difference between the corona discharge electrode(s) and the collector electrode(s). The insulated driver electrode(s) may or may not be at a same voltage potential as the corona discharge electrode, but should be at a different voltage potential than the collector electrode(s).

The insulation (i.e., dielectric material) on the driver electrodes allows the voltage potential to be increased between the driver and collector electrodes, to a voltage potential that would otherwise cause arcing if the insulation were not present. This increased voltage potential increases particle collection efficiency. Additionally, the insulation will reduce, and likely prevent, any arcing from occurring, especially if a carbon path is formed between the collector and driver electrodes, e.g., due to an insect getting caught therebetween.

In accordance with an embodiment of the present invention, the corona discharge electrode(s) and the insulated driver electrode(s) are grounded, while the high voltage source is used to provide a high voltage potential to the collector electrode(s). This is a relatively easy embodiment to implement, since the high voltage source need only provide one polarity.

In accordance with an embodiment of the present invention, the corona discharge electrode(s) is at a first voltage potential, the collector electrode(s) is at a second voltage potential different than the first voltage potential, and the insulated driver electrode is at a third voltage potential different than the first and second voltage potentials. One of the first, second and third voltage potentials can be ground, but need not be. Other variations, such as the corona discharge and driver electrodes being at the same potential (ground or otherwise) are within the scope of the invention.

In accordance with a preferred embodiment of the present invention, the upstream end of each insulated driver electrode is may be set back a distance from the upstream end of the collector electrode(s), it is however within the scope of the invention to have the upstream end of each insulated driver electrode to be substantially aligned with or set forward a distance from the upstream end of the collector electrode, depending upon spacing within the unit.

In accordance with one embodiment of the present invention, an insulated driver electrode includes generally flat elongated sides that are generally parallel with the adjacent collector electrode(s), for example a printed circuit board (pcb). Alternatively, an insulated driver electrode can include one, or preferably a row of, insulated wire-shaped electrodes.

Each insulated driver electrode includes an underlying electrically conductive electrode that is covered with, a dielectric material. The dielectric material can be, for example, an additional layer of insulated material used on a pcb, heat shrink tubing material, an insulating varnish type material, or a ceramic enamel. In accordance with an embodiment of the present invention, the dielectric material may be coated with an ozone reducing catalyst. In accordance with another embodiment of the present invention, the dielectric material may include or is an ozone reducing catalyst.

Other features and advantages of the invention will appear from the following description in which the preferred embodiments have been set forth in detail, in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTIONS OF THE FIGURES

FIG. **1**A illustrates schematically, a conventional ESP system.

FIG. **1**B illustrates exemplary dimensions for the ESP system of FIG. **1**A.

FIG. **2**A illustrates schematically, an ESP system according to an embodiment of the present invention.

FIG. **2**B illustrates exemplary dimensions for the ESP system of FIG. **2**A.

FIG. **2**C is a cross section of an insulated driver electrode, according to an embodiment of the present invention.

FIGS. **3**–**5** illustrate schematically, ESP systems according to alternative embodiments of the present invention.

FIG. **6** illustrates schematically, exemplary electric field lines produced between the various electrodes of the embodiment of the present invention.

FIG. **7** is a cross section of an insulated driver electrode that is coated with an ozone reducing catalyst, according to an embodiment of the present invention.

FIG. **8** illustrates schematically, an ESP device that includes insulated driver electrodes that are made from rows of insulated wire-shaped electrodes, in accordance with an alternative embodiment of the present invention.

FIGS. **9**A and **9**B are graphs that show collection efficiency increase in relation to the collection region electric field increase.

FIG. **10** illustrates schematically, an ESP device in which the collection electric field is increased by moving the electrodes in the collection region closer to one another, in accordance with an embodiment of the present invention. FIG. **10** also includes exemplary dimensions for the ESP system.

FIG. **11** illustrates schematically, further exemplary electric field lines that may be produced between a corona discharge electrode and collector electrodes.

FIG. **12** illustrates schematically, an alternative electrode configuration, in accordance with an embodiment of the present invention, where the ionization region includes its own collector type electrodes.

FIG. **13** illustrates schematically, an ESP system, according to another embodiment of the present invention.

FIG. **14** is a perspective view of an ESP system that includes generally horizontal electrodes, in accordance with an embodiment of the present invention.

FIG. **15** is a perspective view of an ESP system that includes generally vertical electrodes, in accordance with an embodiment of the present invention.

FIG. **16** shows how multiple ESP systems of the present invention can be combined to create a larger ESP system.

FIG. **17** is a perspective view of an exemplary housing for an ESP system, according to an embodiment of the present invention.

DETAILED DESCRIPTION

FIG. **2**A illustrates schematically, an ESP module or system **200**, according to an embodiment of the present invention. The system **200** includes a corona discharge electrode **202** (also known as an emitter electrode) and a plurality of collector electrodes **204**. An insulated driver electrode **206** is located between each pair of collector electrodes. In the embodiment shown there are four collector electrodes **204***a*, **204***b*, **204***c* and **204***d*, and three driver electrodes **206***a*, **206***b* and **206***c*. In this embodiment, the corona discharge electrode **202** is shown as receiving a negative charge. The collector electrodes **204**, which are likely metal plates, are shown as receiving a positive charge. The driver electrodes **206**, which are also likely metal plates, are shown as receiving a negative charge. FIG. **2**B illustrates exemplary dimensions for the system or module of FIG. **2**A. A comparison between FIGS. **1**A and **2**A reveals that the only difference between the two figures is that the driver electrodes in FIG. **2**A are insulated. The use of insulated driver electrodes **206** provides advantages, which are discussed below.

As shown in FIG. **2**C (which is a cross section of an insulated driver electrode **206**), each insulated driver electrode **206** includes an underlying electrically conductive electrode **214** that is covered by a dielectric material **216**. In accordance with one embodiment of the present invention, the electrically conductive electrode is located on a printed circuit board (pcb) covered by one or more additional layers of insulated material **216**. Exemplary insulated pcb's are generally commercially available and may be found from a variety of sources, including for example Electronic Service and Design Corp, of Harrisburg, Pa. Alternatively, the dielectric material could be heat shrink tubing wherein during manufacture, heat shrink tubing is placed over the conductive electrodes **214** and then heated, which causes the tubing to shrink to the shape of the conductive electrodes **214**. An exemplary heat shrinkable tubing is type FP-301 flexible polyolefin tubing available from 3M of St. Paul, Minn.

Alternatively, the dielectric material **216** may be an insulating varnish, lacquer or resin. For example, a varnish, after being applied to the surface of a conductive electrode, dries and forms an insulating coat or film, a few mils (thousands of an inch) in thickness, covering the electrodes **214**. The dielectric strength of the varnish or lacquer can be, for example, above 1000 V/mil (Volts per thousands of an inch). Such insulating varnishes, lacquers and resins are commercially available from various sources, such as from John C. Dolph Company of Monmouth Junction, N.J., and Ranbar Electrical Materials Inc. of Manor, Pa.

Other possible dielectric materials that can be used to insulate the driver electrodes include ceramic or porcelain enamel or fiberglass. These are just a few examples of dielectric materials that can be used to insulate the driver electrodes **206**. It is within the spirit and scope of the present invention that other insulating dielectric materials can be used to insulate the driver electrodes.

During operation of system **200**, the corona discharge electrode **202** and the insulated driver electrodes **206** are negatively charged, and the collector electrodes **206** are positively charged. The same negative voltage can be applied to both the corona discharge electrode **202** and the insulated driver electrodes **206**. Alternatively, the corona discharge electrode **202** can receive a different negative charge than the insulated driver electrodes **206**. In the ionization region **210**, the high voltage potential difference between the corona discharge electrode **202** and the collector electrodes **204** produces a high intensity electric field that is highly concentrated around the corona discharge electrode **202**. More specifically, a corona discharge takes place from the corona discharge electrode **202** to the collector electrodes **204**, producing negatively charged ions. Particles (e.g., dust particles) in the airflow (represented by arrow **250**) that move through the ionization region **210** are negatively charged by the ions. The negatively charged particles are repelled by the negatively charged discharge electrodes **202**, and are attracted to and deposited on the positively charged collector, electrodes **204**.

Further electric fields are produced between the insulated driver electrodes **206** and the collector electrodes **204**, which further push the positively charged particles toward the collector electrodes **204**. Generally, the greater this electric field between the driver electrodes **206** and the collector electrodes **204**, the greater the migration velocity and the particle collection efficiency. Conventionally, the extent that this voltage difference (and thus, the electric field) could be increased was limited because arcing would occur between the collector electrodes and un-insulated driver electrodes beyond a certain voltage potential difference. However, with the present invention, the insulation **216** covering electrical conductor **214** significantly increases the voltage potential difference that can be obtained between the collector electrodes **204** and the driver electrodes **206** without arcing. The increased potential difference results in an increased electric field, which significantly increases particle collecting efficiency. By analogy, the insulation **216** works much the same way as a dielectric material works in a parallel plate capacitor. That is, even though a parallel plate capacitor can be created with only an air gap between a pair of differently charged conductive plates, the electric field can be significantly increased by placing a dielectric material between the plates.

The airflow **250** can be generated in any manner. For example, the air flow could be created with forced air circulation. Such forced are circulation can be created, for example, by a fan upstream from the ionization region **210** pushing the air toward the collecting region. Alternatively, the fan may be located downstream from the ionization region **210** pulling the air toward the collecting region. The airflow may also be generated electrostatically. These examples are not meant to be limiting.

Referring back to FIG. **2**A, a germicidal (e.g., ultra-violet) lamp **230**, can be located upstream and/or downstream from the electrodes, to destroy germs within the airflow. Although the lamps **230** are not shown in many of the following FIGS., it should be understood that a germicidal lamp can be used in all embodiments of the present invention. Additional details of the inclusion of a germicidal lamp are provided in U.S. Pat. No. 6,544,485, entitled "Electro-Kinetic Device with Enhanced Anti-Microorganism Capability," and U.S. patent application Ser. No. 10/074,347, entitled "Electro-Kinetic Air Transporter and Conditioner Device with Enhanced Housing Configuration and Enhanced Anti-Microorganism Capability," each of which is incorporated herein by reference.

FIG. **3** illustrates schematically, an ESP module or system **300** according to another embodiment of the present invention. The arrangement of system **300** is similar to that of system **200** (and thus, is numbered in the same manner), except that the corona discharge electrode **202** and insulated driver electrodes **206** are positively charged, and the collector electrodes **204** are negatively charged.

The ESP system **300** operates in a similar manner to system **200**. More specifically, in the ionization-region **110**, the high voltage potential difference between the corona discharge electrode **202** and the collector electrodes **204** produces a high intensity electric field that is highly concentrated around the corona discharge electrode **202**. This causes a corona discharge to take place from the corona discharge electrode **202** to the collector electrodes **204**, producing positively charged ions. Particles (e.g., dust particles) in the vicinity of the corona discharge electrode are positively charged by the ions. The positively charged particles are repelled by the positively charged discharge electrode **202**, and are attracted to and deposited on the negatively charged collector electrodes **204**. The further electric fields produced between the insulated driver electrodes **206** and collector electrodes **204**, further push the positively charged particles toward the collector electrodes **204**. While system **300** may have a collection efficiency similar to that of system **200**, system **300** will output air that includes excess positive ions, which are less desirable than the negatively charged ions that are produced using system **200**.

FIG. **4** illustrates schematically, an ESP module or system **400**, according to still another embodiment of the present invention. In the arrangement of system **400**, the corona discharge electrode **202** and insulated driver electrodes **206** are grounded, and the collector electrodes **204** are negatively charged. In ESP system **400**, the high voltage potential difference between the grounded corona discharge electrode **202** and the collector electrodes **204** produces a high intensity electric field that is highly concentrated within the ionization region **210** around the corona discharge electrode **202**. More specifically, the corona discharge takes place from the corona discharge electrode **202** to the collector electrodes **204**, producing positive ions. This causes particles (e.g., dust particles) in the vicinity of corona discharge electrode **202** to become positively charged relative to the collector electrodes **204**. These particles are attracted to and deposited on the negatively charged collector electrodes **204**. The further electric fields produced between the insulated driver electrodes **206** and collector electrodes **204**, further push the charged particles toward the collector electrodes **204**.

FIG. **5** illustrates schematically, an ESP module or system **500**, according to a further embodiment of the present invention. The arrangement of system **500** is similar to that of system **400**, except the collector electrodes are now positively charged. System **500** operates similar to system **400**, except system **500** produces excess negative ions, which are preferred to the excess positive ions produced by system **400**.

To summarize, in system **200** shown in FIG. **2**, the corona discharge electrode is negative, the collectors **204** are positive, and the insulated drivers **206** are negative; in system **300** in FIG. **3**, the corona discharge electrode is positive, the collectors **204** are negative, and the insulated drivers **206** are positive; in system **400** of FIG. **4**, the corona discharge electrode is grounded, the collectors **204** are negative, and the insulated drivers **206** are grounded; in system **500** of FIG. **5**, the corona discharge electrode is grounded, the collectors **204** are positive, and the insulated drivers **206** are grounded. In addition to those described above, there are other voltage potential variations that can be used to produce an ESP module or system that includes one or more insulated driver electrodes **206**. For example, it would also be possible to modify the system **200** of FIG. **2** so that the insulated driver electrodes **206** were grounded, or so that the insulated driver electrodes were slightly positive (so long as the collector electrodes **204** were significantly more positive). For another example, it would be possible to modify the system **300** of FIG. **3** so that the insulated driver electrodes **206** were grounded, or so that the insulated driver electrodes were slightly negative (so long as the collector electrodes **204** were significantly more negative). Other variations are also possible while still being within the spirit and scope of the present invention. For example, it is also possible that instead of grounding certain portions of the electrode arrangement, the entire arrangement can float (e.g., the corona discharge electrode **202** and insulated driver electrodes **206** can be at a floating voltage potential, with the collector electrodes **204** offset from the floating voltage potential). What is preferred is that there is a high voltage potential between corona electrode **202** and the collector electrodes **204** such that particles are ionized, and that there is a high voltage potential between the insulated driver electrodes **206** and the collectors **204** to drive the ionized particles toward the collectors **204**.

According to an embodiment of the present invention, if desired, the voltage potential of the corona discharge electrode **202** and the insulated driver electrodes **206** can be independently adjusted. This allows for corona current adjustment (produced by the electric field between the discharge electrode **202** and collector electrodes **204**) to be performed independently of adjustments to the electric fields between the insulated driver electrodes **206** and collector electrodes **204**.

The electric fields produced between the corona discharge electrode **202** and collector electrodes **204** (in the ionization region **210**), and the electric fields produced between the insulated driver electrodes **206** and collector electrodes **204** (in the collector region **220**), are shown by exemplary dashed lines in FIG. **6**. In addition to the electric field being produced between the corona discharge electrode **202** and the outer collector electrodes **204***a* and **204***d*, as shown in FIG. **6**, electric fields (not shown in FIG. **6**) may also be produced between the corona discharge electrode **202** and the upstream ends of the inner collector electrodes **204***b* and **204***c*. This depends on the distance between the corona discharge electrode **202** and the collector electrodes **204***b* and **204***c*.

As discussed above, ionization region **210** produces ions that charge particles in the air that flows through the region **210** in a downstream direction toward the collector region **220**. In the collector region **220**, the charged particles are attracted to the collector electrodes **204**. Additionally, the insulated driver electrodes **206** push the charged particles in the air flow toward the collector electrodes **204**.

Electric fields produced between the insulated driver electrode **206** and collector electrodes **204** (in the collecting region **220**) should not interfere with the electric fields between the corona discharge electrode **202** and the collector electrodes **204** (i.e., the ionization region **210**). If this were to occur, the collecting region **220** would reduce the intensity of the ionization region **210**.

As explained above, the corona discharge electrode **202** and insulated driver electrodes **206** may or may not be at the same voltage potential, depending on which embodiment of the present invention is practiced. When at the same voltage potential, there will be no problem of arcing occurring between the corona discharge electrode **202** and insulated driver electrodes **206**. Further, even when at different potentials, if the insulated driver electrodes **206** are setback as described above, the collector electrodes **204** will shield the insulated driver electrodes **206**. Thus, as shown in FIG. **6**, there is generally no electric field produced between the corona discharge electrode **202** and the insulated driver electrodes **206**. Accordingly, arcing should not occur therebetween.

In addition to producing ions, the systems described above will also produce ozone (O_3). While limited amounts of ozone are useful for eliminating odors, concentrations of ozone beyond recommended levels are generally undesirable. In accordance with embodiments of the present invention, ozone production is reduced by coating the insulated driver electrodes **206** with an ozone reducing catalyst. Exemplary ozone reducing catalysts include manganese dioxide and activated carbon. Commercially available ozone reducing catalysts such as PremAir™ manufactured by Englehard Corporation of Iselin, N.J., can also be used. Where the insulated driver electrodes **206** are coated with an ozone reducing catalyst, the ultra-violate radiation from a germicidal lamp may increase the effectiveness of the catalyst. The inclusion of a germicidal lamp **230** is discussed above with reference to FIG. **2**A.

Some ozone reducing catalysts, such as manganese dioxide are not electrically conductive, while others, such as activated carbon are electrically conductive. When using a catalyst that is not electrically conductive, the insulation **216** can be coated in any available manner because the catalyst will act as an additional insulator, and thus not defeat the purpose of adding the insulator **216**. However, when using a catalyst that is electrically conductive, it is important that the electrically conductive catalyst does not interfere with the benefits of insulating the driver. This will be described with reference to FIG. **7**.

Referring now to FIG. **7**, the underlying electrically conductive electrode **214** is covered by dielectric insulation **216** to produce an insulated driver electrode **206**. The underlying driver electrode **214** is shown as being connected by a wire **702** (or other conductor) to a voltage potential (ground in this example). An ozone reducing catalyst **704** covers most of the insulation **216**. If the ozone reducing catalyst does not conduct electricity, then the ozone reducing catalyst **704** may contact the wire or other conductor **702** without negating the advantages provided by insulating the underlying driver electrodes **214**. However, if the ozone reducing catalyst **704** is electrically conductive, then care must be taken so that the electrically conductive ozone reducing catalyst **704** (covering the insulation **216**) does not touch the wire or other conductor **702** that connects the underlying electrically conductive electrode **214** to a voltage potential (e.g., ground, a positive voltage, or a negative voltage). So long as an electrically conductive ozone reducing catalyst does not touch the wire **704** that connects the driver electrode **214** to a voltage potential, then the potential of the electrically conductive ozone reducing catalyst will remain floating, thereby still allowing an increased voltage potential between insulated driver electrode **206** and adjacent collector electrodes **204**. Other examples of electrically conductive ozone reducing catalyst include, but are not limited to, noble metals.

In accordance with another embodiment of the present invention, if the ozone reducing catalyst is not electrically conductive, then the ozone reducing catalyst can be included in, or used as, the insulation **216**. Preferably the ozone reducing catalysts should have a dielectric strength of at least 1000 V/mil (one-hundredth of an inch) in this embodiment.

If an ozone reducing catalyst is electrically conductive, the collector electrodes **204** can be coated with the catalyst. However, it is preferable to coat the insulated driver electrodes **206** with an ozone reducing catalyst, rather than the collector electrodes **204**. This is because as particles collect on the collector electrodes **204**, the surfaces of the collector electrodes **204** become covered with the particles, thereby reducing the effectiveness of the ozone reducing catalyst. The insulated driver electrodes **206**, on the other hand, do not collect particles. Thus, the ozone reducing effectiveness of a catalyst coating the insulated driver electrodes **206** will not diminish due to being covered by particles.

In the previous FIGS., the insulated driver electrodes **206** have been shown as including a generally plate like electrically conductive electrode **214** covered by a dielectric insulator **216**. In alternative embodiments of the present invention, the insulated driver electrodes can take other forms. For example, referring to FIG. **8**, the driver electrodes can include a wire or rod-like (collectively referred to as wire-shaped) electrical conductor covered by dielectric insulation. Although a single wire-shaped insulated driver electrode can be used, it is preferable to use a row of such wire-shaped insulated electrodes to form insulated drivers electrodes, shown as **206*a*'**, **206*b*'** and **206*c*'** in FIG. **8**. The electric field between such insulated driver electrodes **206'** and the collector electrodes **204** will look similar to the corresponding electric fields shown in FIG. **6**.

Tests have been performed that show the increased particle collecting efficiency that can be achieved using insulated driver electrodes **206**. In these tests, forced air circulation (specifically, a fan) was used to produce an airflow velocity of 500 feet per minute (fpm). This is above the recommended air velocity for a conventional ESP system, since this high a velocity can cause dust particles collected on the collector electrodes to become dislodged and reintroduced into the air stream. Additionally, higher air velocities typically lower collecting efficiency since it is harder to capture fast moving particles (e.g., due to more kinetic force to overcome, and less time to capture the particles). Conventional commercially available ESP systems more likely utilize air velocities between 75 fpm and 390 fpm, depending on model and the selected air speed (e.g., low, medium or high). The higher than normal airflow velocity was intentionally used in these tests to reduce overall efficiency, and thereby make it easier to see trends in the test results.

The system used in the tests resembled the system **200** shown in FIGS. **2**A, having the dimensions shown in FIG. **2**B. Tests were also performed using the conventional system **100** shown in FIG. **1**A, having the dimensions shown in FIG. **1**B. In these tests, the depth of the electrodes (e.g., in the Z direction, into the page) was about 5". With system **100**, breakdown (i.e., arcing) between the collector electrodes **104** and un-insulated driver electrodes **106** occurred when the electric field in the collecting region **120** exceeded 1.2 kV/mm. With an electric field of 1.2 kV/mm in the collecting region **120**, the collecting efficiency of 0.3 μm particles was below 0.93.

By using insulated driver electrodes **206**, the electric field in the collating region **220** was able to be increased to about 2.4 kV/mm without breakdown (i.e., arcing) between the collector electrodes **204** and insulated driver electrodes **206**. The graph of FIG. **9**A shows collecting efficiency (for 0.3 μm particles) versus the collecting region electric field (in KV/mm) for system **200**. As can be seen in FIG. **9**A, the collecting efficiency increased in a generally linear fashion as the electric field in the collecting region **220** was increased (by increasing the high voltage potential difference between the collector electrodes **204** and insulated driver electrodes **206**). More specifically, for 0.3 μm particles, the collecting efficiency was able to be increased to more than 0.98. The graph of FIG. **9**B shows that collecting efficiency is generally greater for larger particles. FIG. **9**B also shows that even for larger particles, collecting efficiency increases with an increased electric field in the collecting region **220**.

As shown by the above described test results, insulated driver electrodes **206** can be used to increase collecting efficiency by enabling the electric field in a collecting region **220** to be increased beyond what has been possible without insulated driver electrodes **206**. The resultant increase in electrical field between the driver electrodes **206** and collector electrodes **204**, exceeds those associated with or found in conventional ESP systems and correspondingly results in increased collection efficiency where all other factors are held constant, (e.g. air speed, particle size, etc.). Thus, for an ESP system of given dimensions, the use of insulated driver electrodes **206** may significantly increase particle collection efficiency.

Insulated driver electrodes **206** can alternatively be used to reduce the length of collecting electrodes **204**, while maintaining an acceptable efficiency. For example, assume that for a particular application an acceptable particle collection efficiency for 0.3 μm particles is about 0.93. By using insulated driver electrodes **206** (as opposed to non-insulated driver electrode **106**), the electric field in the collection region can be increased from 1.2 kV/mm to 2.4 kV/mm, which allows collecting electrodes (and driver electrodes) to be made 3 times shorter while maintaining the efficiency that would be achieved using the 1.2 kV/mm electric field. This is possible, in part, because the particle migration velocity increases as the electric field increases.

The relationship between voltage potential difference, distance and electric field is as follows: $E=V/d$, where E is electric field, V is voltage potential difference, and d is distance. Thus, the electric field within the collecting region **220** can be increased (e.g., from 1.2 kV/mm to 2.4 kV/mm) by doubling the potential difference between the collector electrodes **204** and insulated driver electrodes **206**. Alternatively the electric field can be doubled by decreasing (i.e., halving) the distance between the collectors **204** and insulated driver **206**. A combination of adjusting the voltage potential difference and adjusting the distance is also practical.

Another advantage of reducing the distance between collector electrodes **204** and insulated driver electrodes **206** is that more collector electrodes can be fit within given dimensions. An increased number of collector electrodes increases the total collecting surface area, which results in increased collecting efficiency. For example, FIG. **10** shows how the number of collector electrodes could be doubled while keeping the same overall dimensions as the ESP systems in FIGS. **1**B and **2**B.

Embodiments of the present invention relate to the use of insulated driver electrodes in ESP systems. The precise arrangement of the corona discharge electrode **202**, the collector electrodes **204** and the insulated driver electrodes **206** shown in the FIGS. discussed above are exemplary. Other electrode arrangements would also benefit from using insulated driver electrodes. For example, in most of the above discussed FIGS., the ESP systems include one corona discharge electrode **102**, four collector electrodes **204** and three insulated driver electrodes **206**. In FIG. **10**, the number of collector electrodes **204** was increased to seven, and the number of insulated driver electrodes **206** was increased to six. These are just exemplary configurations. Preferably there are at least two collector electrodes **204** for each corona discharge electrode **202**, and there is an insulated driver electrode **206** preferably located between each adjacent pair of collector electrodes **204**, as shown in the FIGS. The collector electrodes **204** and insulated driver electrodes **206** preferably extend in a downstream direction from the corona discharge electrode **202**, so that the collecting region **220** is downstream from the ionization region **210**.

In the above discussed FIGS. the outermost collector electrodes (e.g., **204***a* and **204***d* in FIG. **2**A) are shown as extending further upstream then the innermost collector electrodes (e.g., **204***b* and **204***c* in FIG. **2**B). This arrangement is useful to creating an ionization electric field, within the ionization region **210**, that charges particles within the airflow **250**. However, such an arrangement is not necessary. For example, as mentioned above in the discussion of FIG. **6**, and as shown by dashed lines in FIG. **11**, an ionization electric field can also be created between the corona discharge electrode **202** and the upstream ends of the collectors electrodes **204**, if they are sufficiently close to the corona discharge electrode **202**.

As shown in FIG. **12**, it is also possible that the ionization region **210** includes separate collecting electrodes **1204** to produce the ionization electric field.

FIG. **13** shows an exemplary embodiment of the present invention that includes a single corona discharge electrode **202**, a pair of collector electrodes **204**, and a single insulated driver electrode **206**. Other numbers of corona discharge electrodes **202**, collector electrodes **204**, and insulated driver electrodes are also within the spirit and scope of the present. For example, there can be multiple corona discharge electrodes **202** in the ionization region.

In the various electrode arrangements described herein, the corona discharge electrode **202** can be fabricated, for example, from tungsten. Tungsten is sufficiently robust in order to withstand cleaning, has a high melting point to retard breakdown due to ionization, and has a rough exterior surface that seems to promote efficient ionization. A corona discharge electrode **202** is likely wire-shaped, and is likely manufactured from a wire or, if thicker than a typical wire, still has the general appearance of a wire or rod. Alternatively, as is known in the art, other types of ionizers, such as pin or needle shaped electrodes can be used in place of a wire. For example, an elongated saw-toothed edge can be used, with each edge functioning as a corona discharge point. A column of tapered pins or needles would function similarly. As another alternative, a plate with a sharp downstream edge can be used as a corona discharge electrode. These are just a few examples of the corona discharge electrodes that can be used with embodiments of the present invention. Further, other materials besides tungsten can be used to produce the corona discharge electrode **202**.

In accordance with an embodiment of the present invention, collector electrodes **204** have a highly polished exterior surface to minimize unwanted point-to-point radiation. As such, collector electrodes **204** can be fabricated, for example, from stainless steel and/or brass, among other materials. The polished surface of collector electrodes **204** also promotes ease of electrode cleaning. The collector electrodes **204** are preferably lightweight, easy to fabricate, and lend themselves to mass production. The collector electrodes can be solid. Alternatively, the collector electrodes may be manufactured from sheet metal that is configured to define side regions and a bulbous nose region, forming a hollow elongated shaped or "U"-shaped electrode. When a U-shaped electrode, the collector will have a nose (i.e., rounded end) and two trailing sides (which may be bent back to meet each other, thereby forming another nose). Similarly, in embodiments including plate like insulated driver electrodes **206**, the underlying driver electrodes can be made of a similar material and in a similar shape (e.g., hollow elongated shape or "U" shaped) as the collector electrodes **204**.

The corona discharge electrode(s) **202**, collector electrodes **204** and insulated driver electrode(s) **206** may be generally horizontal, as shown in FIG. **14**. Alternatively, the corona discharge electrode(s) **202**, collector electrodes **204** and insulated driver electrode(s) **206** may be generally vertical, as shown in FIG. **15**. Of course, it is also possible that the electrodes are neither vertical nor horizontal (i.e., they can be slanted or diagonal). Preferably the various electrodes are generally parallel to one another so that the electric field strength is generally evenly distributed.

The corona discharge electrode(s) **202**, the collector electrodes **204** and the insulated driver electrode(s) **206**, collectively referred to as an ESP electrode assembly, can be located within a freestanding housing that is meant to be placed within a room, to clean the air within the room. Depending on whether the electrode assembly is horizontally arranged (e.g., as in FIG. **13**) or vertically arranged (e.g., as in FIG. **14**), the housing may be more elongated in the horizontal direction or in the vertical direction. It is possible to rely on ambient air pressure to channel air through the unit, such as that found in a room where very little current exists and the air pressure remains relatively constant or on cyclical air pressure, such as that created by a breeze or natural air movement such as through a window. Alternatively it may be desirable to use forced air circulation to process a larger amount of air. If forced air circulation is to be used, the housing will likely include a fan that is upstream of the electrode assembly. An upstream fan **1402** is shown in FIGS. **14** and **15**. If a fan that pulls air is used (as opposed to a fan that pushes air), the fan may be located downstream from the electrode assembly. Within the housing there will also likely be one more high voltage sources that produce the high voltage potentials that are applied to the various electrodes, as described above. The high voltage source(s) can be used, for example, to convert a nominal 110 VAC (from a household plug) into appropriate voltage levels useful for the various embodiments of the present invention. It is also possible that the high voltage source(s) could be battery powered. High voltage sources are well known in the art and have been used with ESP systems for decades, and thus need not be described in more detail herein. Additional details of an exemplary housing, according to an embodiment of the present invention, is discussed below with reference to FIG. **17**.

The use of an insulated driver electrode, in accordance with embodiments of the present invention, would also be useful in ESP systems that are installed in heating, air conditioning and ventilation ducts.

In most of the FIGS. discussed above, four collector electrodes **204** and three insulated driver electrodes **206** were shown, with one corona discharge electrode **202**. As mentioned above, these numbers of electrodes have been shown for example, and can be changed. Preferably there is at least a pair of collector electrodes with an insulated driver electrode therebetween to push charged particles toward the collector electrodes. However, it is possible to have embodiments with only one collector electrode **204**, and one or more corona discharge electrodes **202**. In such embodiments, the insulated driver electrode **206** should be generally parallel to the collector electrode **204**. Further, it is within the spirit and scope of the invention that the corona discharge electrode **202** and collector electrodes **204**, as well as the insulated driver electrodes **206**, can have other shapes besides those specifically mentioned herein.

A partial discharge may occur between a collecting electrode **204** and an insulated driver electrode **206** if dust or carbon buildup occurs between the collecting electrode **204** and the insulated driver electrode **206**. More specifically, it is possible that the electric field in the vicinity of such buildup may exceed the critical or threshold value for voltage breakdown of air (which is about 3 kV/mm), causing ions from the collecting electrode **204** to move to the insulated driver **206** and get deposited on the insulation **216**. Thus, the electric field gets redistributed in that the field becomes higher inside the insulation **216** and lower in the air until the field gets lower than the threshold value causing voltage breakdown. During the partial discharge, only the small local area where breakdown happens has some charge movement and redistribution. The rest of the ESP system will work normally because the partial discharge does not reduce the voltage potential difference between the collector electrode **204** and the underlying electrically conductive portion **214** of the insulated driver electrode **206**.

As shown in FIG. **16**, many of the ESP modules or systems of the present invention, described above, can be combined to produce larger ESP systems that include multiple sub-ESP modules. For example, multiple (e.g., N) ESP modules (e.g., 200, 300, 400, 500 etc.) can be located one next to another, and/or one above another, to produce a physically larger ESP system that accepts a greater airflow area. Additionally (or alternatively), one or more ESP modules (e.g., M) can be located downstream from one another in a serial fashion. The one or more downstream ESP modules will likely capture any particles that escape through the upstream ESP module(s). In accordance with embodiments of the present invention, multiple ESP modules are housed within a common housing, with the multiple ESP modules (or portions of the ESP modules) collectively removable for cleaning.

Collector electrodes **204** should be cleaned on a regular basis so that particles collected on the electrodes are not reintroduced into the air. It would also be beneficial to clean the corona discharge electrodes **202**, as well as the insulated driver electrodes **206** from time to time. Cleaning of the electrodes can be accomplished by removing the electrodes from the housing within which they are normally located. For example, as disclosed in the application and patent that were incorporated by reference above, a user-liftable handle can be affixed the collector electrodes **204**, which normally rest within a housing. Such a handle member can be used to lift the collectors **204** upward, causing the collector electrodes **204** to telescope out of the top of the housing and, if desired, out of the housing. In other embodiments, the electrodes may be removable out of a side or bottom of the housing, rather than out the top. The corona discharge electrode(s) **202** and insulated driver electrodes **206** may remain within the housing when the collectors **204** are removed, or may also be removable. The entire electrode assembly may be collectively removable, or each separate type of electrodes may be separately removable. Once removed, the electrodes can be cleaning, for example, using a damp cloth, by running the electrodes under water, or by putting the electrodes in a dish washer. The electrodes should be fully dry before being returned to the housing for operation.

FIG. **17** illustrates an exemplary housing **1702** that includes a back **1708**, a front **1710**, a top **1712** and a bottom or base **1714**. The top **1712** includes an opening **1716** through which an electrode assembly **1706** (or portion thereof) can be removed. A handle **1706** can be used to assist with removal of the electrode assembly **1704**. The opening **1716** can alternatively be on a side, or through the bottom **1714**, so that the assembly **1704** can be removed out a side, or out the bottom **1714**.

The removable electrode assembly **1704** can include one or more ESP modules (sometimes also referred to as cells), as was described above with reference to FIG. **16**, with each ESP module including one or more corona discharge electrode **202**, collector electrode **204** and insulated driver electrode **206**. Alternatively, the removable portion of the electrode assembly **1704** can include only collector electrode(s) **204**, or collector electrode(s) **204** and insulated driver electrode(s) **206**, with the corona discharge electrode (s) **202** (and possible insulated driver electrode(s) **206**) remaining in the housing when the assembly **1704** is removed for cleaning. A fan **1402** can be used to push air, or pull air, past the electrodes of the electrode assembly **1704**, as was described above. The back **1708** and front **1710** of the housing **1702** preferably allow air to flow in and out of the housing **1702**, and thus will likely include one or more vents, or can include a grill. As shown in dashed line, a germicidal lamp **230** can be included within the housing, to further condition the airflow.

The housing **1702** can be an upstanding vertically elongated housing, or a more box like housing that is generally shaped like a square. Other shapes are of course possible, including but not limited to for example an elongated horizontal unit, a circular unit, a spiral unit, other geometric shapes and configurations or even a combination of any of these shapes. It is to be understood that any number of shapes and/or sizes could be utilized in the housing without departing from the spirit and scope of the present invention. The housing **1702** can also be a freestanding stand alone type housing, so that it can be placed on a surface (e.g., floor, counter, shelf, etc.) within a room. In one embodiment, the housing **1702** can be sized to fit in or on a window sill, in a similar fashion to a window unit air conditioning cooling unit. It is even possible that the housing **1702** is a small plug-in type housing that includes prongs that extend therefrom, for plugging into an electrical socket. In another embodiment, a cigarette lighter type adapter plug extends from a small housing so that the unit can be plugging into an outlet in an automobile.

In another embodiment, the housing **1702** can be fit within a ventilation duct, or near the input or output of an air heating furnace. When used in a duct, the electrode assembly **1704** may simply be placed within a duct, with the duct acting as the supporting housing for the electrode assembly **1704**.

The foregoing descriptions of the preferred embodiments of the present invention have been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations will be apparent to the practitioner skilled in the art. Modifications and variations may be made to the disclosed embodiments without departing from the subject and spirit of the invention as defined by the following claims. Embodiments were chosen and described in order to best describe the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention, the various embodiments and with various modifications that are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed:

1. An electrostatic precipitator (ESP) system, comprising:

a corona discharge electrode;

a pair of collector electrodes;

an insulated driver electrode located between said pair of collector electrodes;

a first high voltage source coupled between said corona discharge electrode and said pair of collector electrodes, said first high voltage source configured to provide a first high voltage potential difference between said corona discharge electrode and said pair of collector electrodes; and

a second high voltage source coupled between said pair of collector electrodes and said insulated driver electrode, said second high voltage source configured to provide a second high voltage potential difference between said pair of collector electrodes and said insulated driver electrode.

2. The system of claim **1**, wherein said pair of collector electrodes extend in a downstream direction away from said corona discharge electrode, and wherein said system further comprises a fan to produce a flow of air in said downstream direction.

3. The ESP system of claim **2**, wherein:

said corona discharge electrode produces a corona discharge that imparts a charge on particles in the air that flows past said corona discharge electrode;

said insulated driver electrode repels the charged particles toward said collector electrodes; and

said collector electrodes attract and collect at least a portion of the charged particles.

4. The system of claim **1**, wherein:

a first voltage potential difference exists between said corona discharge electrode and said pair of collector electrodes; and

a second voltage potential difference exists between said insulated driver electrode and said pair of collector electrodes, said first and second voltage potentials differences being substantially the same.

5. The system of claim **3**, wherein:

a first voltage potential difference exists between said corona discharge electrode and said pair of collector electrodes; and

a second voltage potential difference exists between said insulated driver electrode and said pair of collector electrodes, said first voltage potential difference being different than said second voltage potentials difference.

6. The system of claim **1**, wherein said corona discharge electrode and said insulated driver electrode are at the same voltage potential.

7. The system of claim **6**, wherein said high voltage source also provides the high voltage potential difference between said collector electrodes and said insulated driver electrode.

8. The system of claim **1**, wherein said corona discharge electrode and said insulated driver electrode are at different voltage potentials.

9. The system of claim **1**, wherein said corona discharge electrode and said insulated driver electrode are at a same voltage potential.

10. The system of claim **1**, wherein:

said corona discharge electrode is at a first voltage potential;

said pair of collector electrodes are at a second voltage potential different than said first voltage potential; and

said insulated driver electrode is at a third voltage potential different than said first and second voltage potentials.

11. The system of claim **1**, wherein the insulated driver electrode is coated with an ozone reducing catalyst.

12. The system of claim **1**, wherein the insulated driver electrode includes an electrically conductive electrode covered by a dielectric material.

13. The system of claim **12**, wherein the dielectric material is coated with an ozone reducing catalyst.

14. The system of claim **12**, wherein the dielectric material comprises a non-electrically conductive ozone reducing catalyst.

15. The system of claim **12**, wherein the electrically conductive electrode of the insulated driver electrode includes generally flat elongated sides that are generally parallel with said collector electrodes.

16. The system of claim **1**, wherein said insulated driver electrode includes at least one wire shaped electrode covered by a dielectric material.

17. The system of claim **1**, wherein the driver electrode includes a row of wire shaped electrodes each covered by a dielectric material, said row being generally parallel to said collector electrodes.

18. The system of claim **1**, wherein said insulated driver electrode is located downstream from said corona discharge electrode.

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